2

Full Surface Interferometric Testing of Grazing Incidence Mirrors

Final Report

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Final Report Abstract and Executive Summary

The aim of this six month SDIO SBIR contract was to demonstrate the proof-of-principle of the "Full Surface Interferometric Scanner" (FSIS), an instrument which can rapidly and reliably measure both the full surface figure as well as the macroroughness of grazing incidence optics. The FSIS has the potential to fill the need of SDIO to characterize and qualify the necessary off-axis aspherical mirror technology that will be used for weapon pointing, beam control, and beam propagation through several environments and countermeasures.

This instrument design is based on the use of normal incidence, sub-aperture interferometry and wavefront shearing interferometry which surmounts many of the problems encountered by other (eg, long trace profilers) techniques. This new system, the FSIS, for which we have developed a breadboard system which makes novel use of three sequential operations: sub-aperture slope measurement, wavefront integration, and surface profile synthesis.

The FSIS breadboard construction was completed during December 1989 and tests were carried out on various optical components such as those typically used for imaging X-ray and hard UV-radiation at grazing incidence. These tests were extended through February 15, 1990, at which time the first phase of the project was concluded.

During the last period of this research project additional development of the software algorithms was carried out; a source code listing is enclosed in this report.

From our tests on various optical surfaces it appears that the FSIS will find application in X-ray and UV high resolution lithography, medical imaging, astronomy, physics, microbiology, and industrial (surface) quality control.

During Phase II two completely automated prototype versions of a rugged and self-contained FSIS will be developed to measure a broad range of grazing incidence optical surfaces.

Achievement of the Phase I Objectives

The Phase I objective was to design, construct, and test an instrument that would be capable of measuring the full surface figure and macroroughness (mm spatial frequency surface error) for aspheric grazing incidence optics. This instrument, the FSIS, was built in a breadboard configuration and measurements were carried out on (cylindrical) sub-aperture segments. Several of these sub-aperature can be synthesized in the software. These measurements can be rapidly carried out (in under 1 second) thereby minimizing sensitivity to thermal fluctuations as well as to other environmental effects that have seriously impaired the effective operation of other instruments. This very short measurement time is necessary when attemping to measure the figure of optical surfaces to the tolerances necessary for grazing incidence X-ray and UV wavelengths in addition to imaging at other wavelengths by off-axis aspheric optics.

For very large mirrors which are greater than the size of the beam width, the full surface scanning capability was achieved through the use of fitting algorithms for overlapping sub-apertures which allowed the full surface shape to be synthesized. A least squares fit is currently being used for the Phase I proof-of-principle demonstration.

During the phase II work more sophisticated algorithms corresponding to particular aspheric surfaces will be tested and their accuracy evaluated. Additional improvements will be made in through the use of a higher resolution CCD camera, improved video frame grabbing and enhanced signal processing.

The present (Phase I) breadboard system stage was not motorized and the system was manually operated. The Phase II instruments will be fully motorized and automated.

Description of the Interferometer Breadboard

A schematic diagram of the interferometer system is shown in figure 1 and was described in detail in the interim report (December, 1989). A photograph of this system is shown in figure 2. To allow for the necessary degrees of freedom a five axis mirror holding system was designed and constructed and includes;

1) An in-plane rotation to align the mirror on to a cylindrical reference surface.

2) A two axis tilt

3) A two axis translation

A photograph of the assembly is shown in figure 3.

The phase shifting was obtained by the appropriate translation of the grating which served as the shearing device.

The test surface was the convex surface of a cylindrical lens having a 500mm focal length and a 250mm radius of curvature.

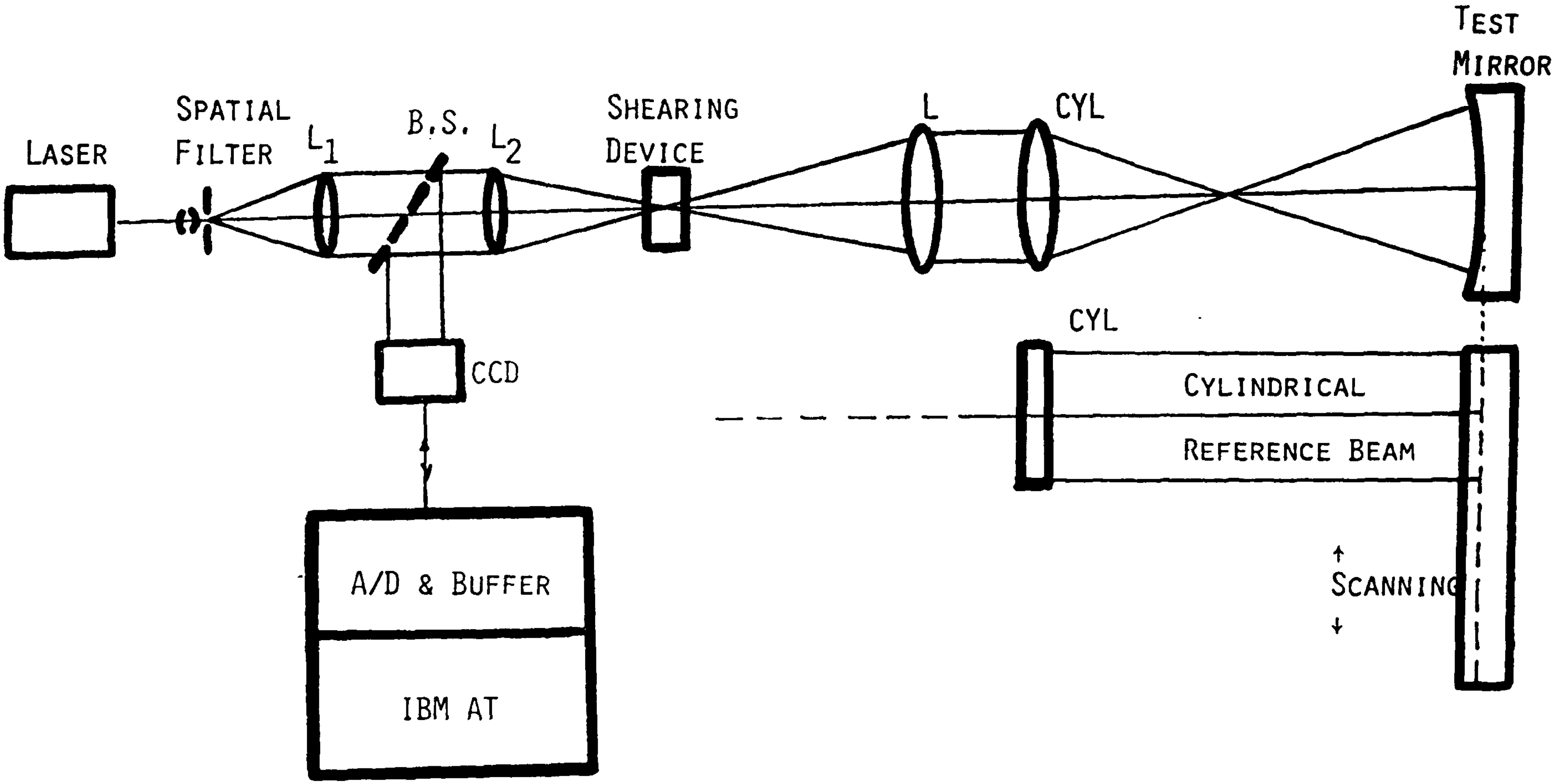


FIGURE 1: SCHEMATIC DIAGRAM OF INTERFEROMETER FOR FULL SURFACE TESTING OF CYLINDRICAL TYPE MIRRORS

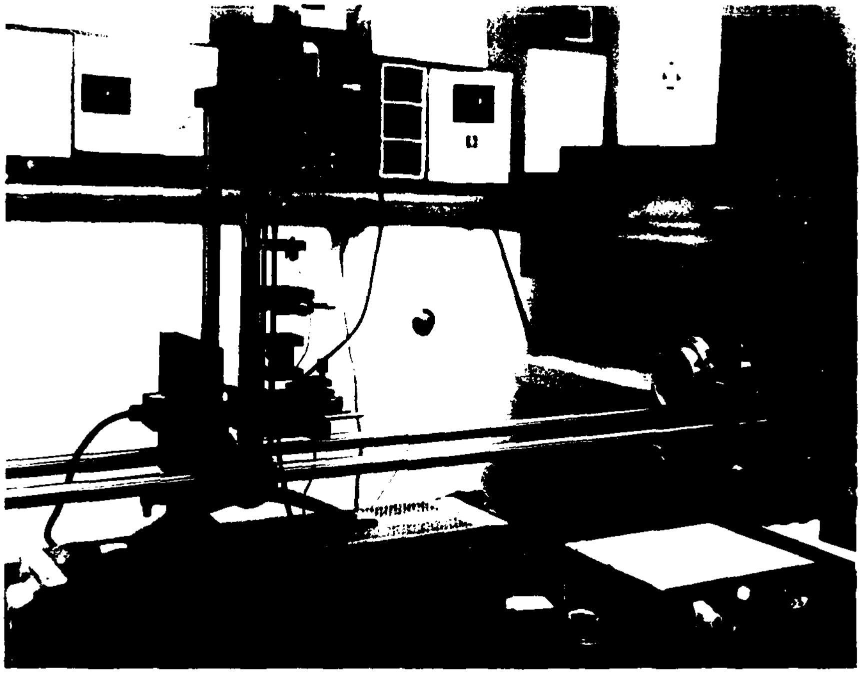


FIGURE 2: PHOTOGRAPH OF COMPLETE INTERFEROMETER BREADBOARD

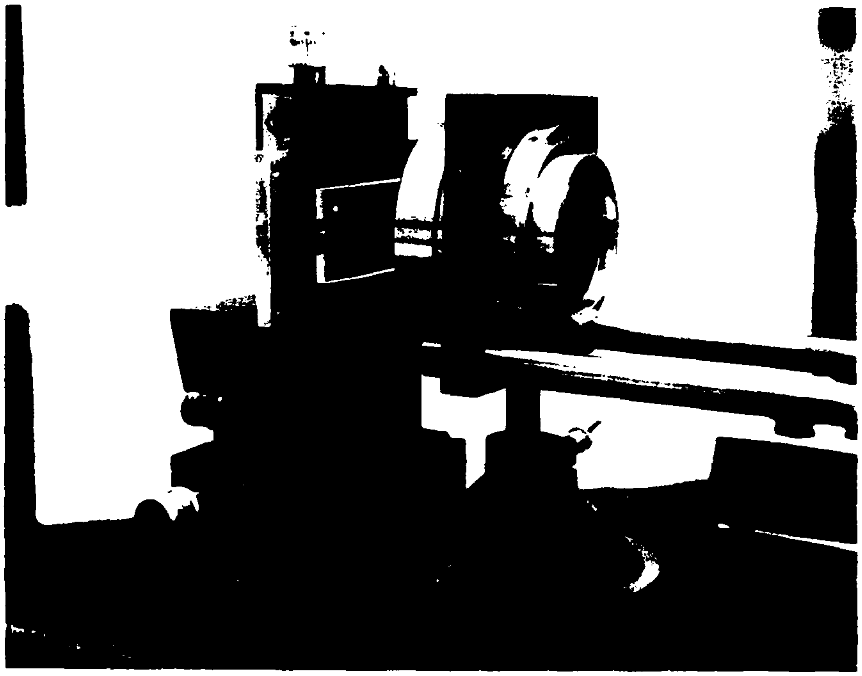


FIGURE 3 : DETAILED VIEW OF CYLINDRICAL MIRROR HOLDING ASSEMBLY (5 AXES : IN-PLANE ROTATION, 2 TILTS AND 2 TRANSLATIONS)

Testing and Data Reduction

In order to appropriately test the FSIS on our sample optic, four cases were considered:

1. The mirror assembly is in-focus and the mirror surface well with the reference surface.
2. The mirror assembly is in-focus, but the surface was misaligned by 1^0 with respect to the reference surface.
3. The mirror assembly was out-of-focus and the surface well aligned with the reference surface.
4. The mirror assembly was out-of-focus and the surface was misaligned by 1^0 with respect to the reference surface.

Figures 4, 8, 12, and 16 and figures 6, 10, 14, and 18 show photographs of the corresponding interferograms for X-shear and Y-shear respectively, ie, the X and Y slope functions.

Figures 5, 9, 13, and 17 and 7, 11, 15, and 19 show the phase measurement of the corresponding interferograms for the X-shear and Y-shear respectively. Each phase interferogram has the :

A) Original, 3-D plot.
B) Tilt removed, 3-D plot.
C) Original, contour plot.
D) Tilt removed, contour plot.

The interferograms were imaged on to a CCD camera, A/D converted and stored in a frame buffer. Phase measurement was then carried out digitally and the results shown in the accompanying figures. These results show in particular that these interferometer measurements are insensitive to focus or mirror alignment. This is in strong contrast to the scanning interferometer sytems.

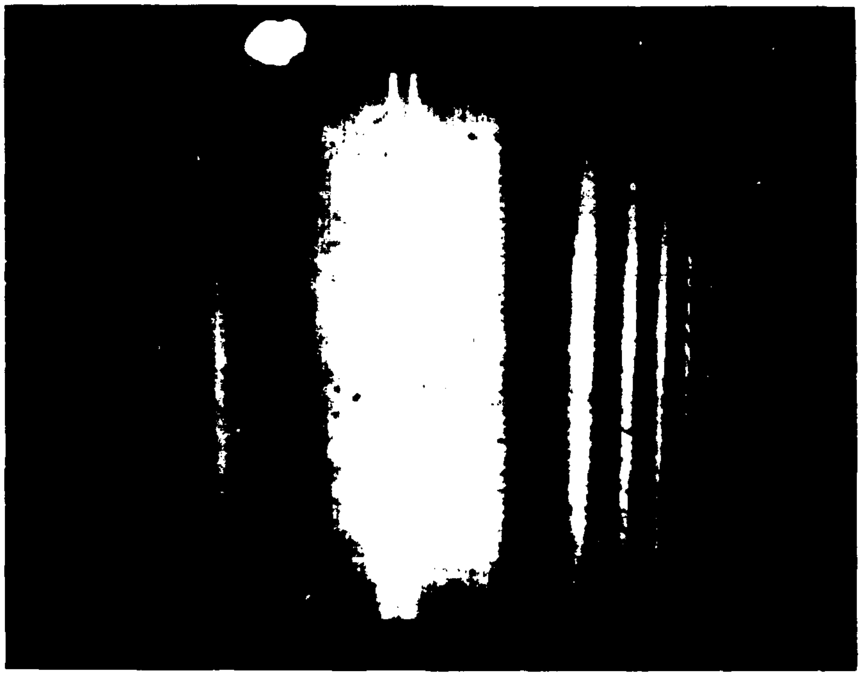


FIGURE 4: X-SHEAR INTERFEROGRAM (CURVED SIDE OF CYLINDER), WITH MIRROR IN FOCUS AND ALIGNED

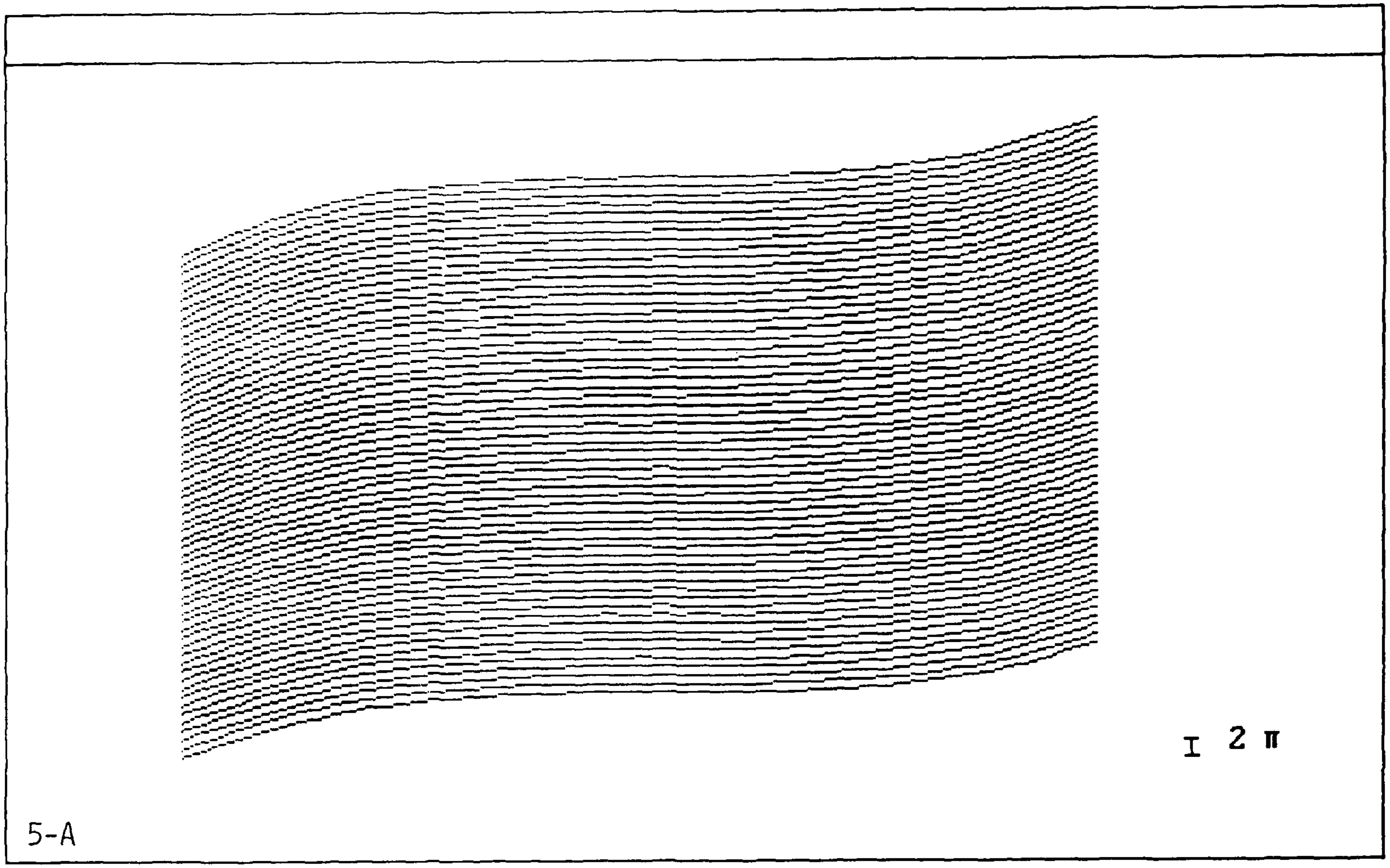
FIGURE 5: PHASE MEASUREMENT FOR X-SHEAR INTERFEROGRAM (FIG.4)

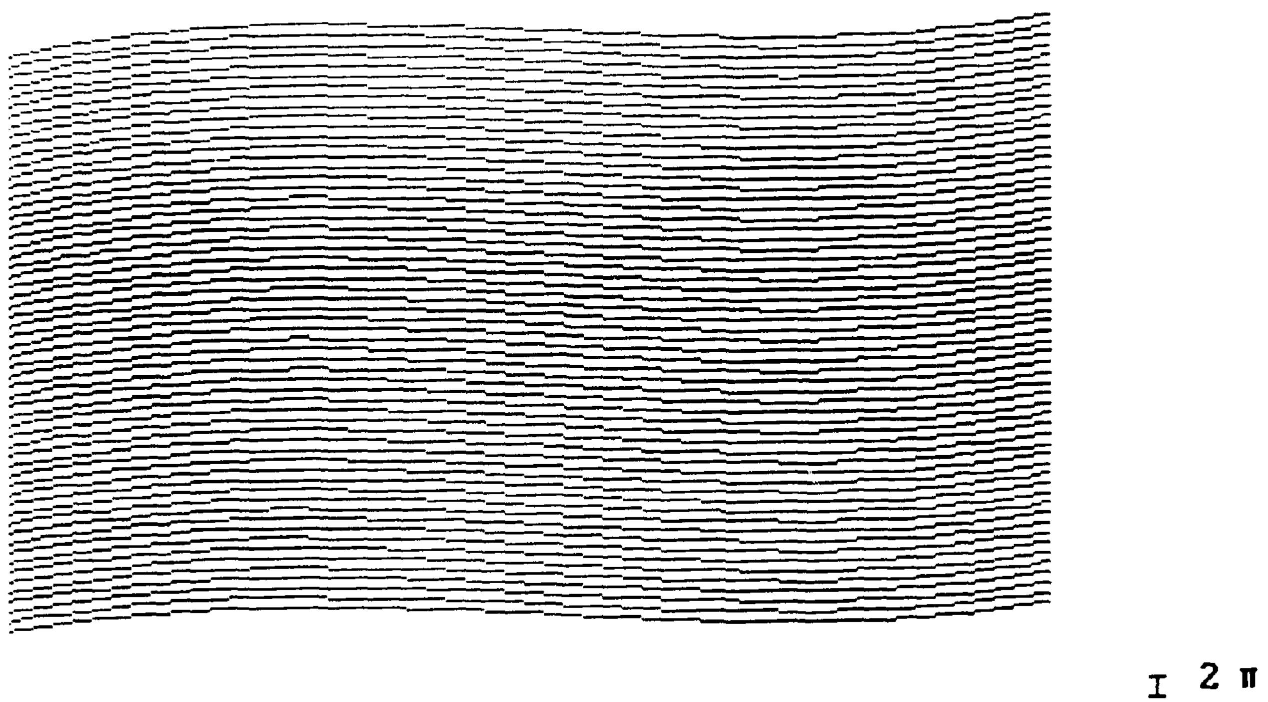
5-A: ORIGINAL, 3-D PLOT

5-B: TILT REMOVED, 3-D PLOT

5-C: ORIGINAL, CONTOUR PLOT

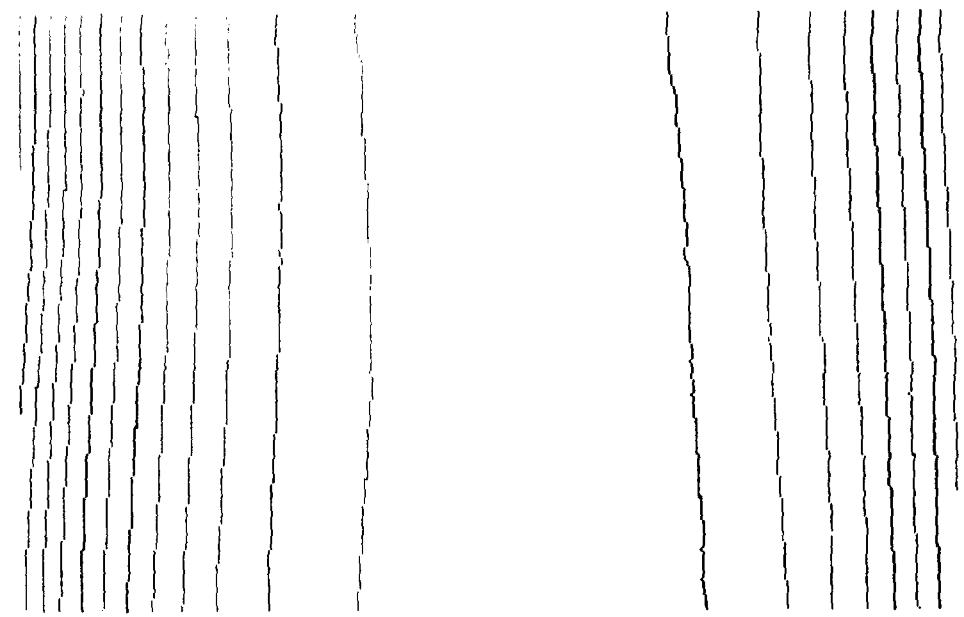
5-D: TILT REMOVED, CONTOUR PLOT


I 2 π
5-A



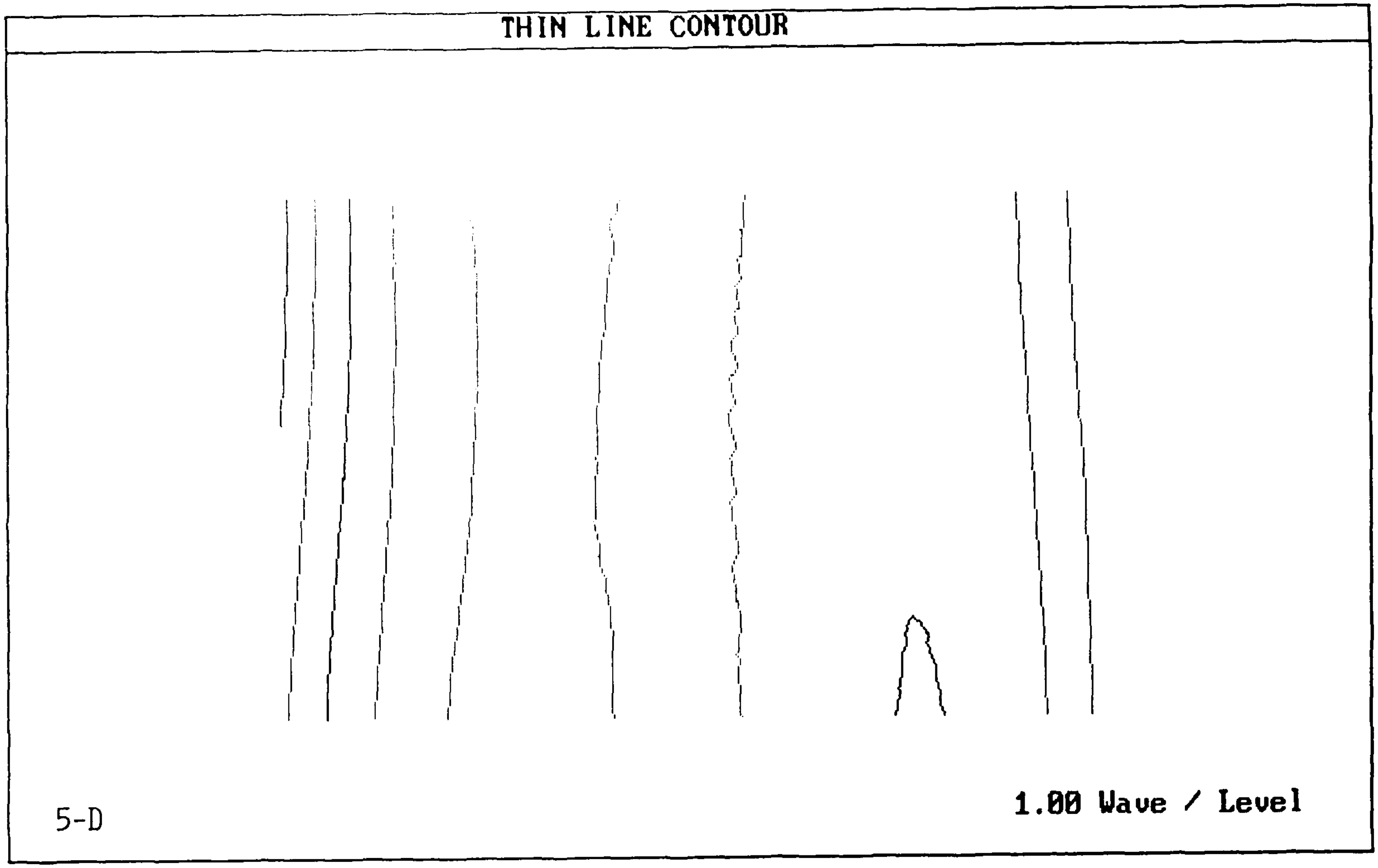
5-B

THIN LINE CONTOUR



5-C

1.00 Wave / Level


THIN LINE CONTOUR
5-D
1.00 Wave / Level

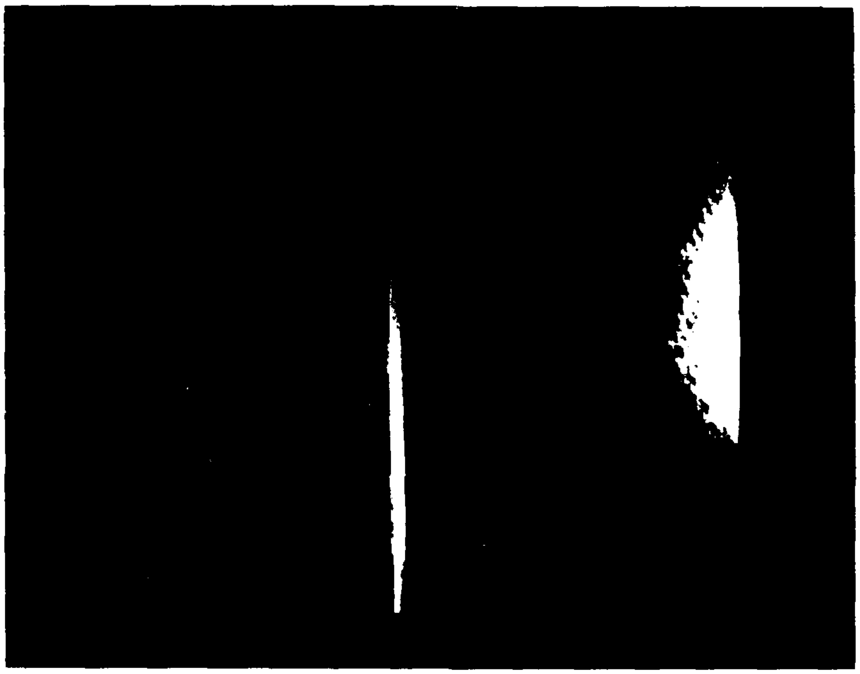


FIGURE 6: Y-SHEAR INTERFEROGRAM (STRAIGHT SIDE OF CYLINDER), WITH MIRROR IN-FOCUS AND ALIGNED

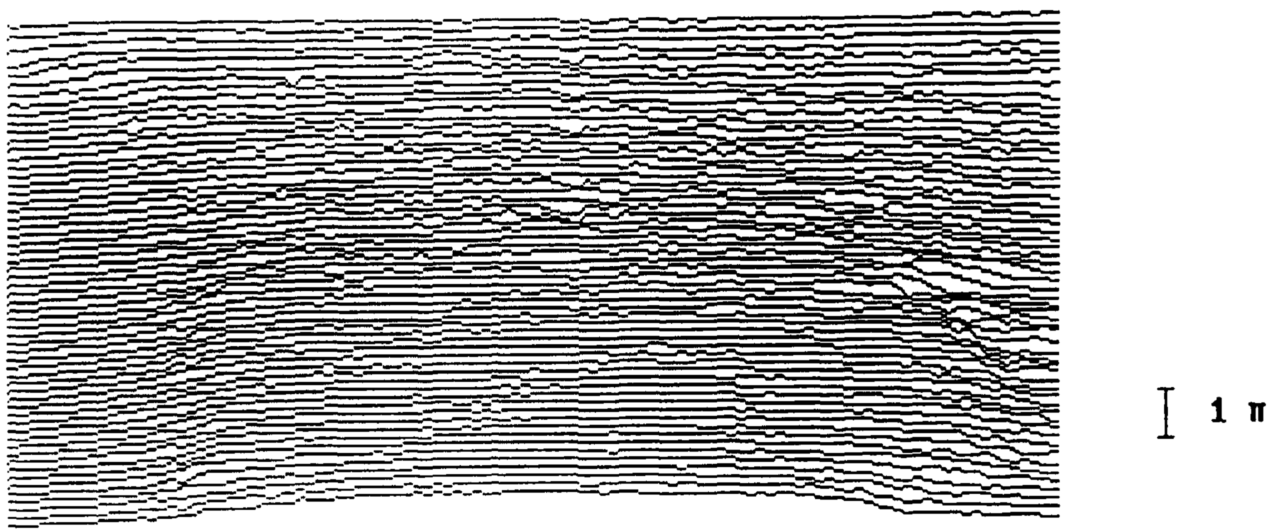
FIGURE 7: PHASE MEASUREMENT FOR Y-SHEAR INTERFEROGRAM (FIG.6)

7-A: ORIGINAL, 3-D PLOT

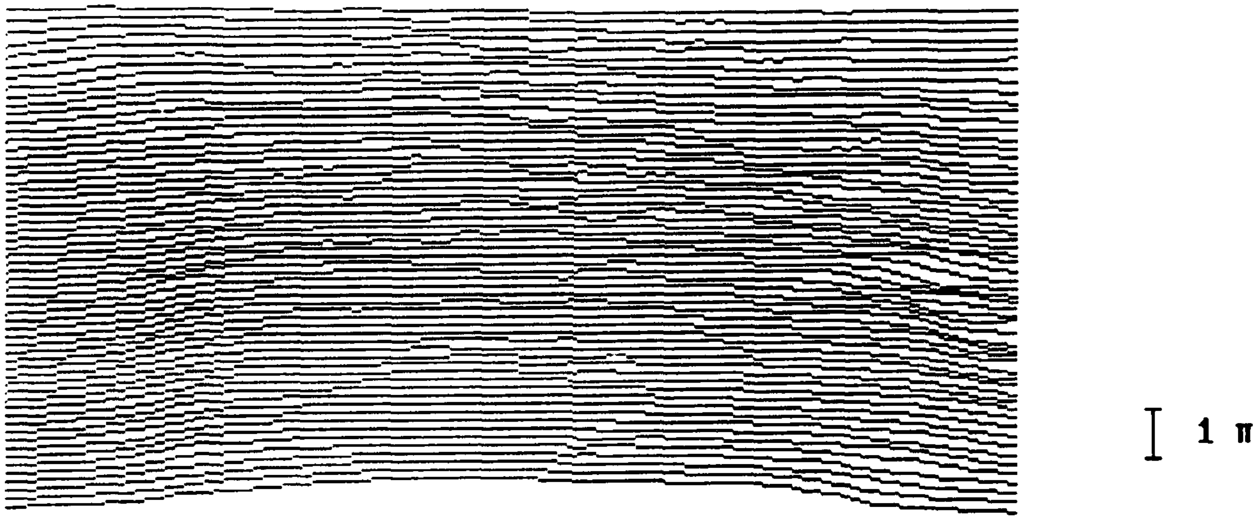
7-B: TILT REMOVED, 3-D PLOT

7-C: ORIGINAL, CONTOUR PLOT

7-D: TILT REMOVED, CONTOUR PLOT



7-A

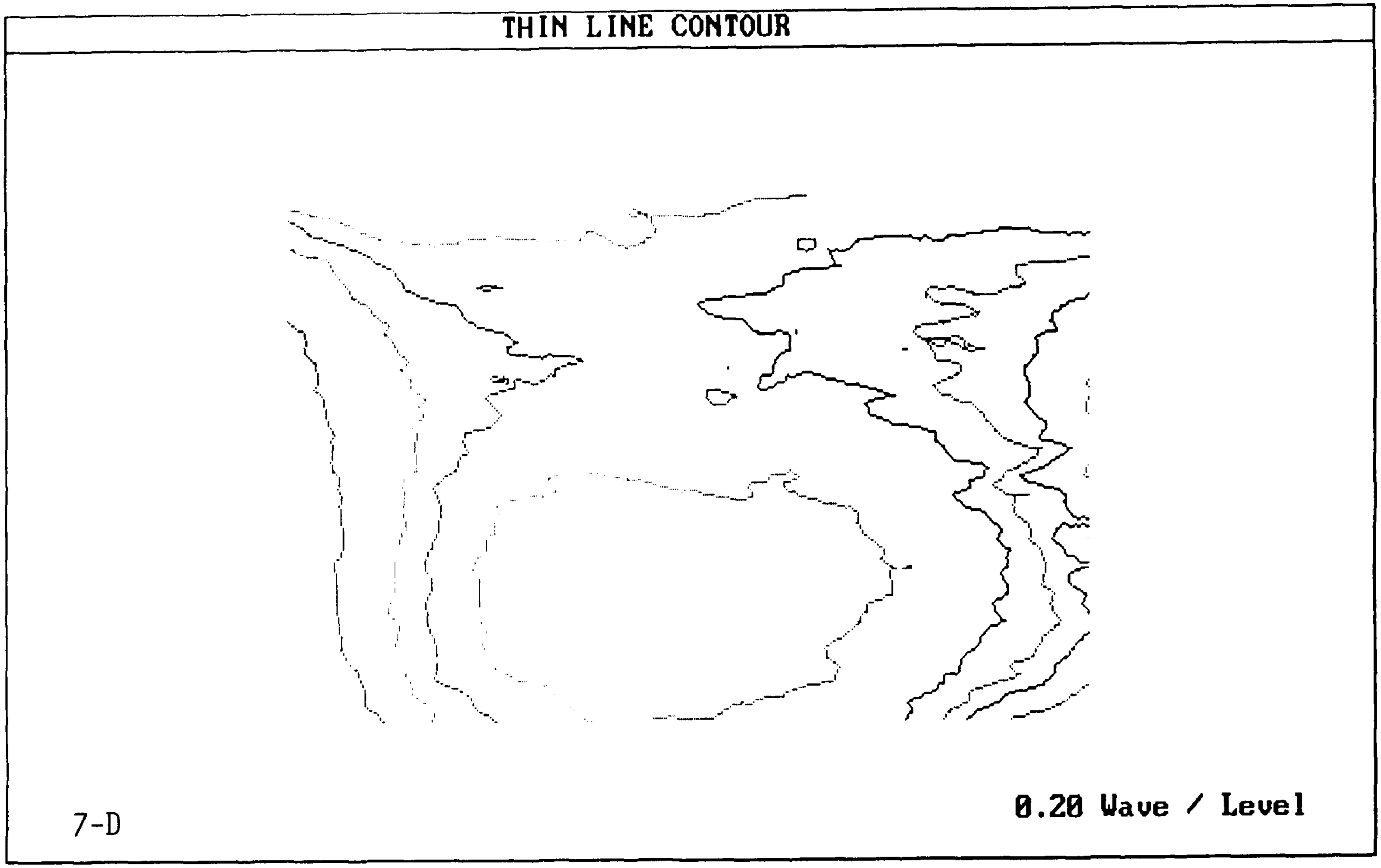


7-B

THIN LINE CONTOUR

7-C

0.20 Wave / Level


THIN LINE CONTOUR
0.20 Wave / Level
7-D

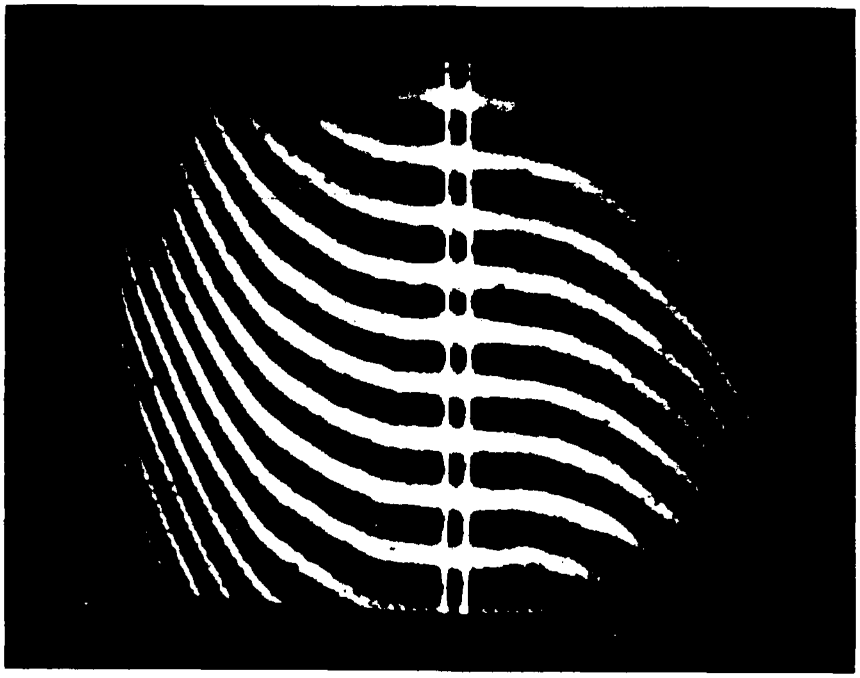


FIGURE 8: X-SHEAR INTERFEROGRAM (CURVED SIDE OF CYLINDER), WITH MIRROR IN-FOCUS AND MISALIGNED BY 1°

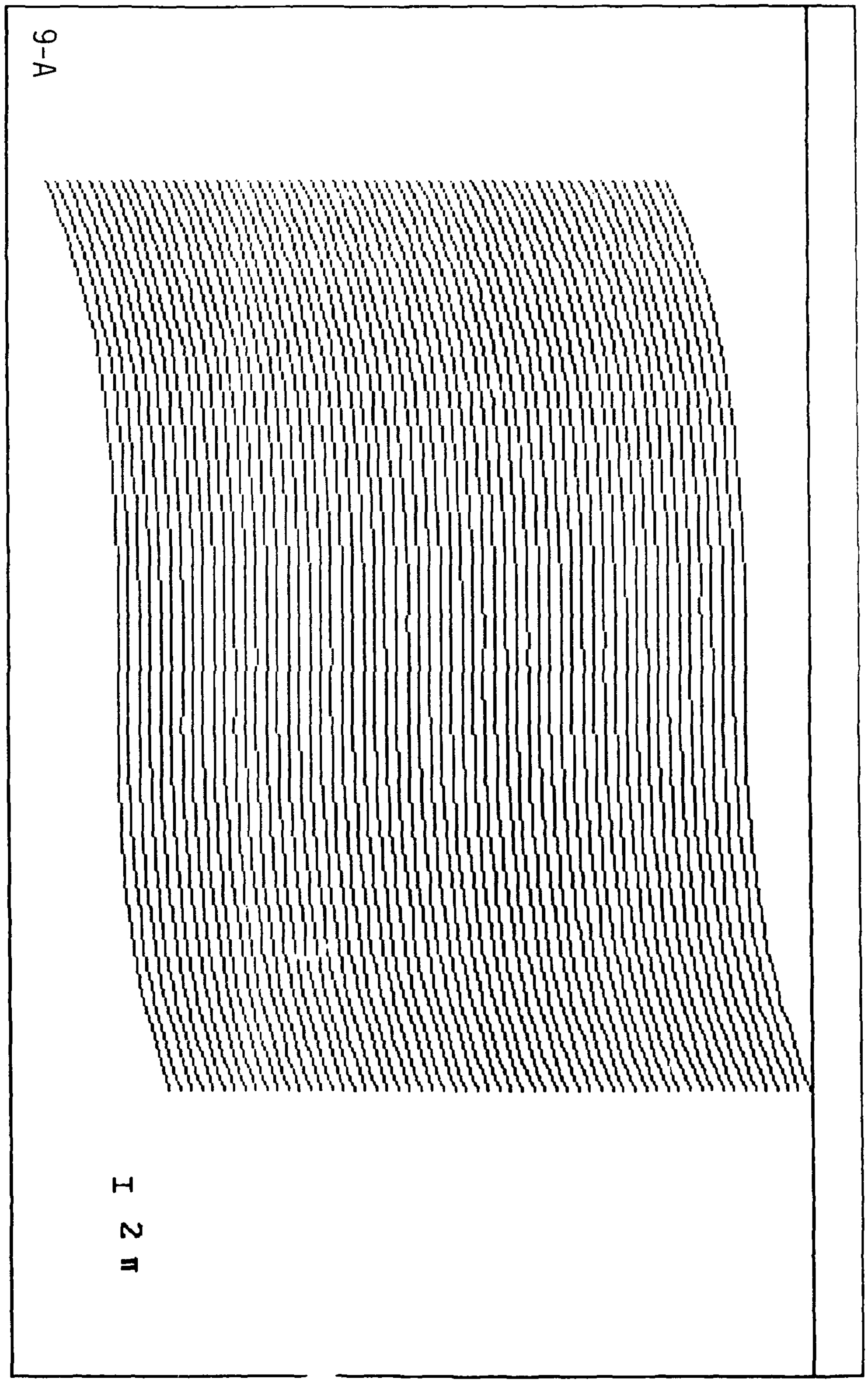
FIGURE 9: PHASE MEASUREMENT FOR X-SHEAR INTERFEROGRAM (FIG.8)

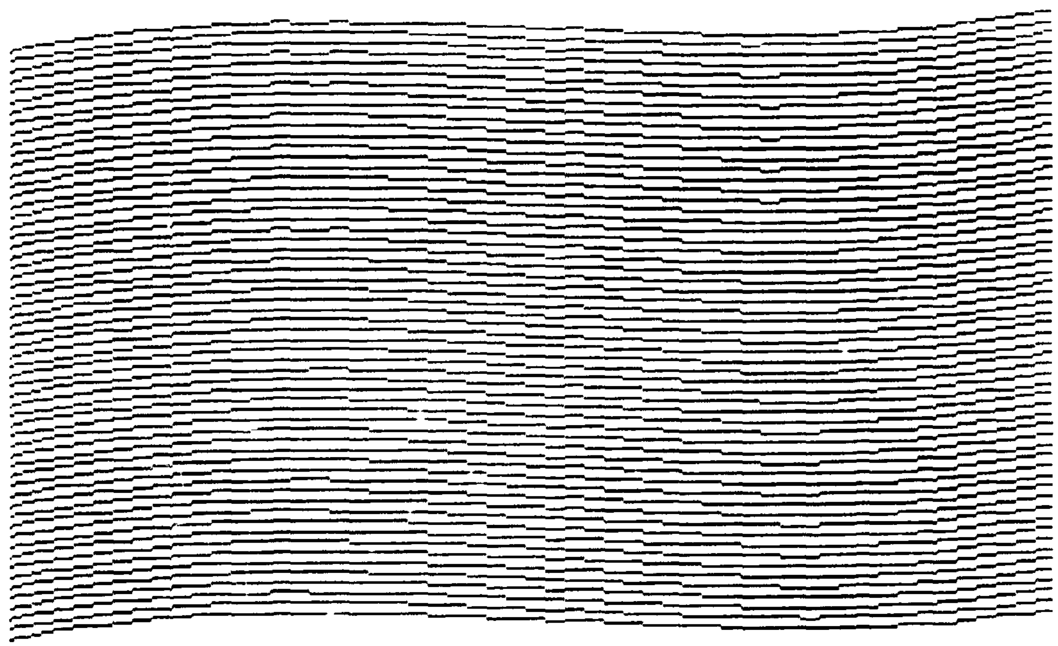
9-A: ORIGINAL 3-D PLOT

9-B: TILT REMOVED, 3-D PLOT

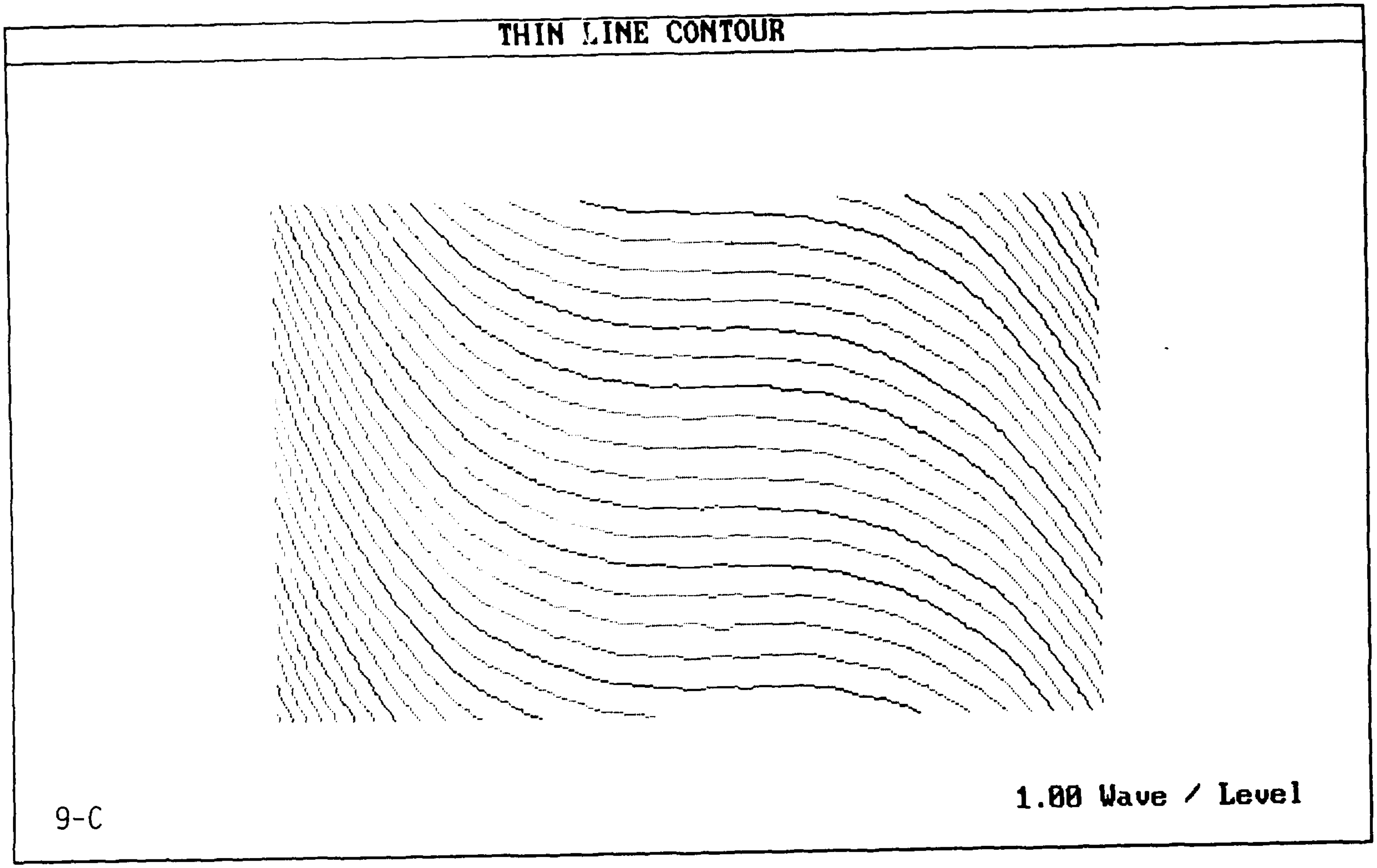
9-C: ORIGINAL, CONTOUR PLOT

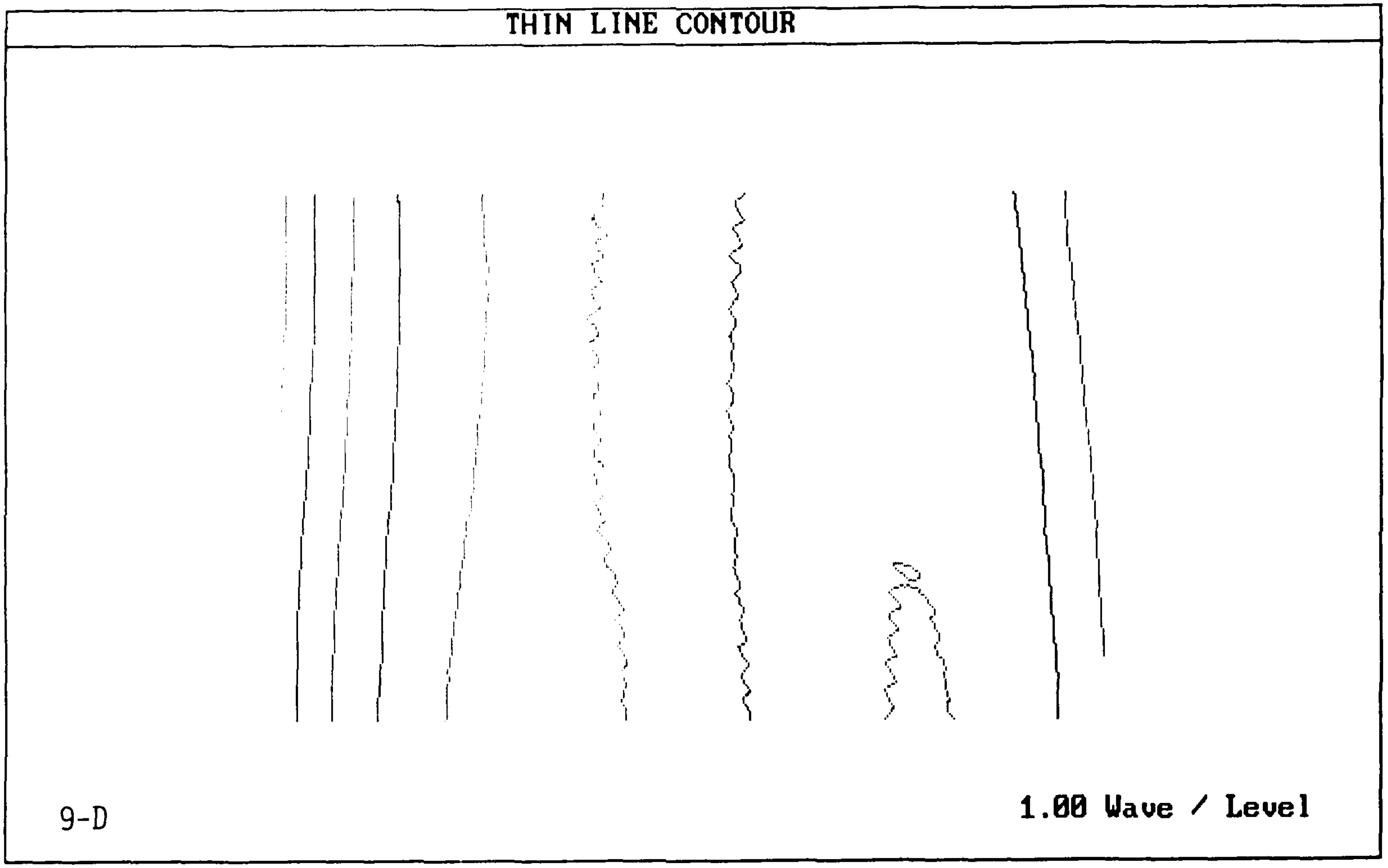
9-D: TILT REMOVED, CONTOUR PLOT


9-A
I 2 π



9-B


THIN LINE CONTOUR
9-C
1.00 Wave / Level


THIN LINE CONTOUR
9-D
1.00 Wave / Level

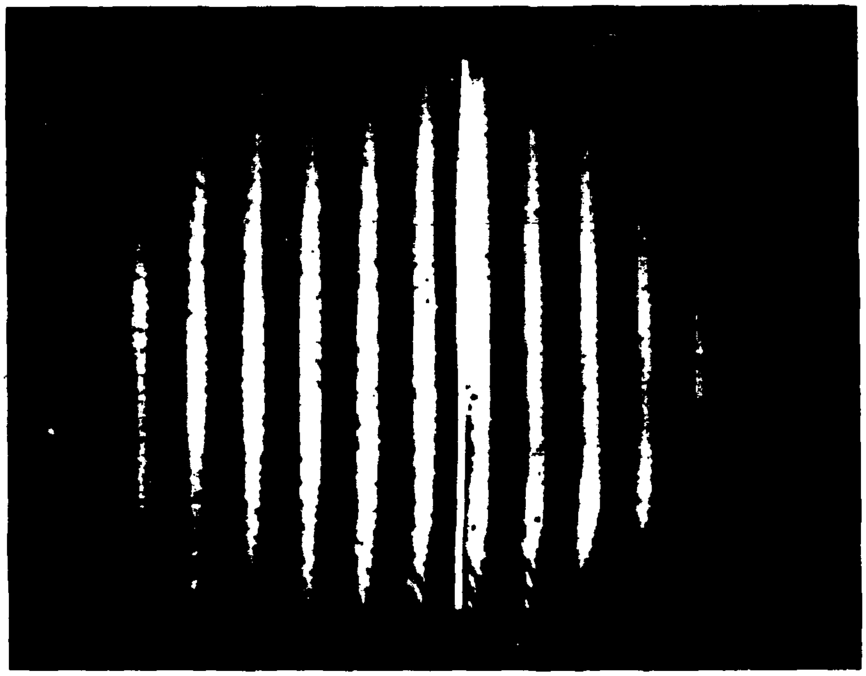


FIGURE 10: Y-SHEAR INTERFEROGRAM (STRAIGHT SIDE OF CYLINDER), WITH MIRROR IN-FOCUS AND MISALIGGNED BY 1°

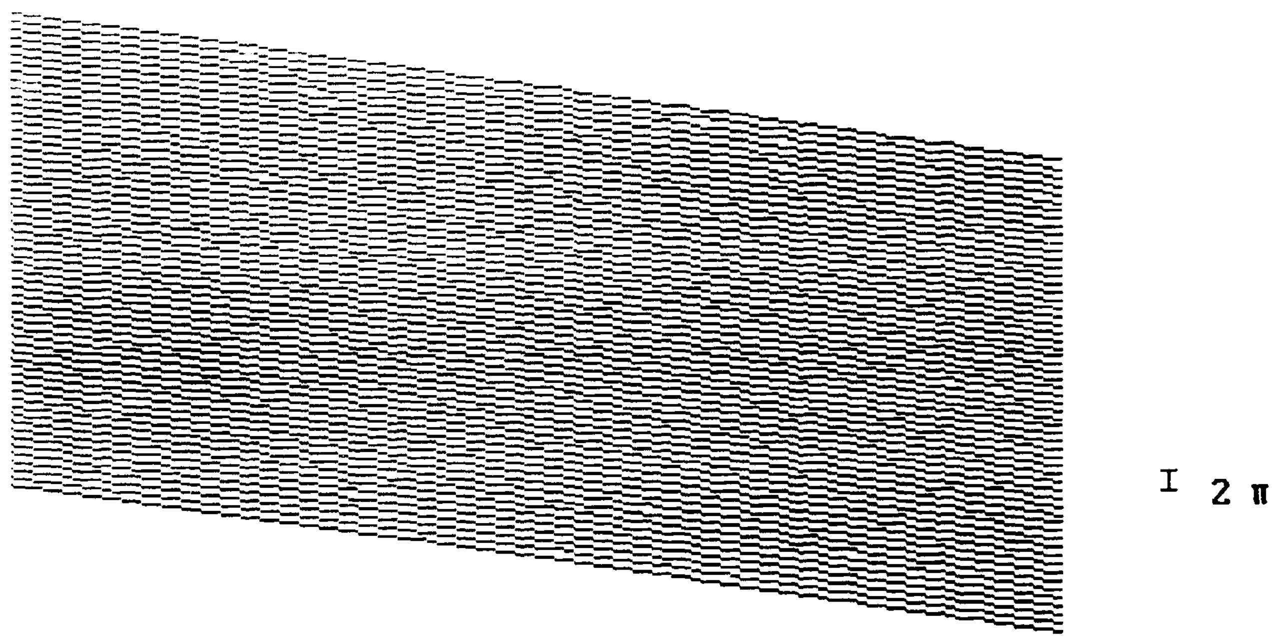
FIGURE 11: PHASE MEASUREMENT OF Y-SHEAR INTERFEROGRAM (FIG.10)

11-A: ORIGINAL, 3-D PLOT

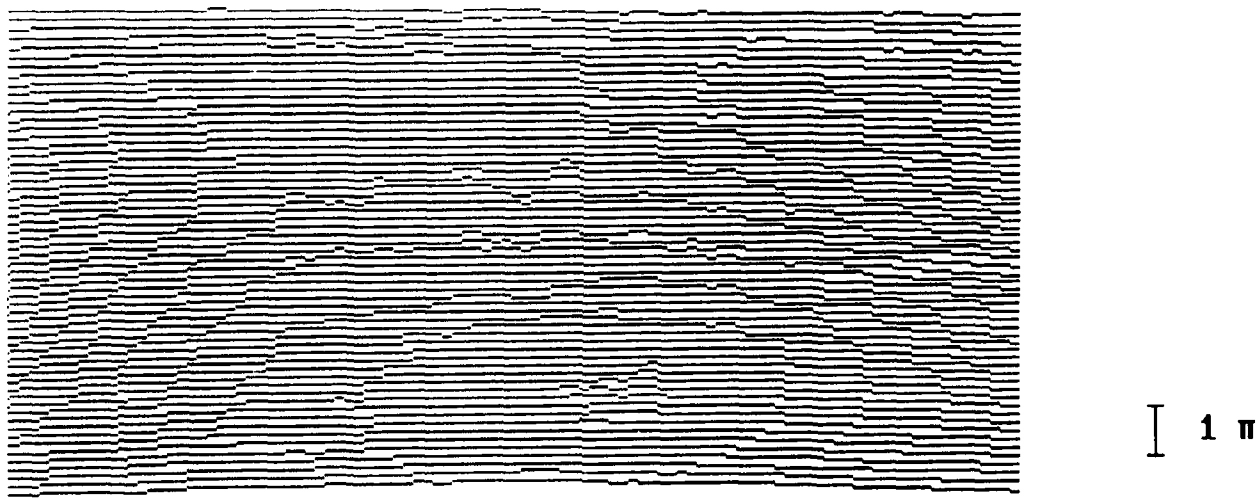
11-B: TILT REMOVED, 3-D PLOT

11-C: ORIGINAL, CONTOUR PLOT

11-D: TILT REMOVED, CONTOUR PLOT

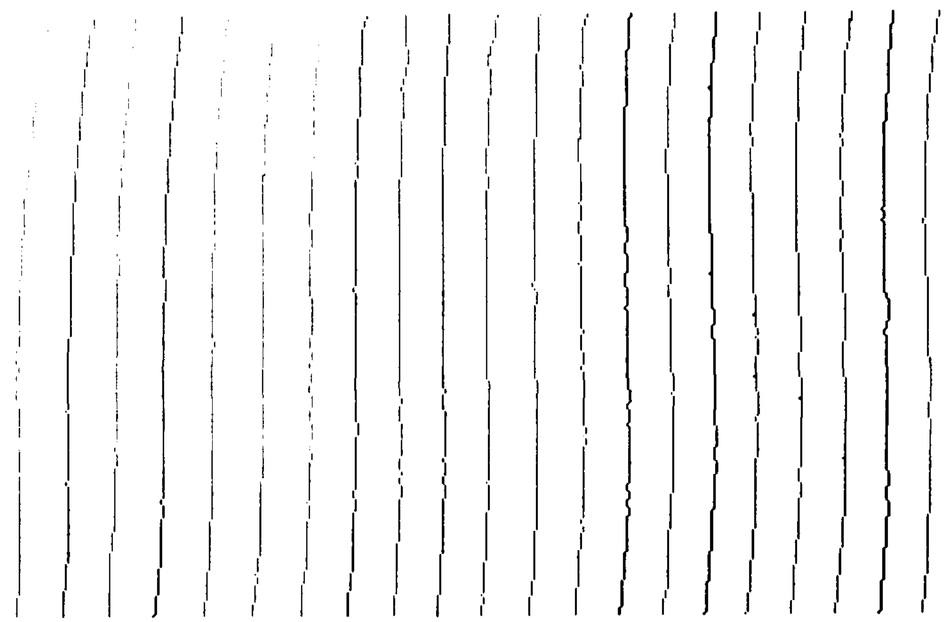


11-A



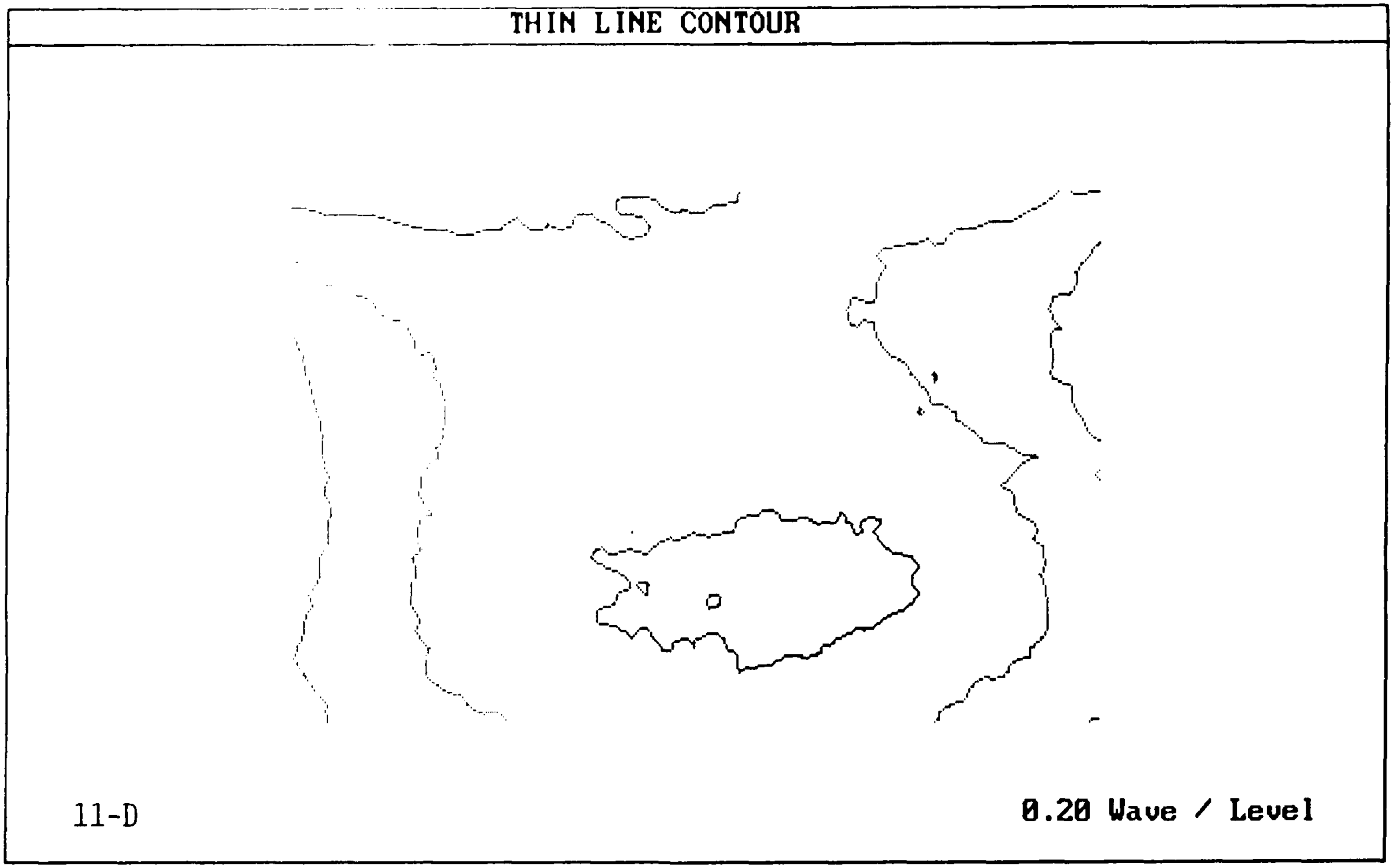
11-B

THIN LINE CONTOUR



11-C

1.00 Wave / Level


THIN LINE CONTOUR
11-D
0.20 Wave / Level

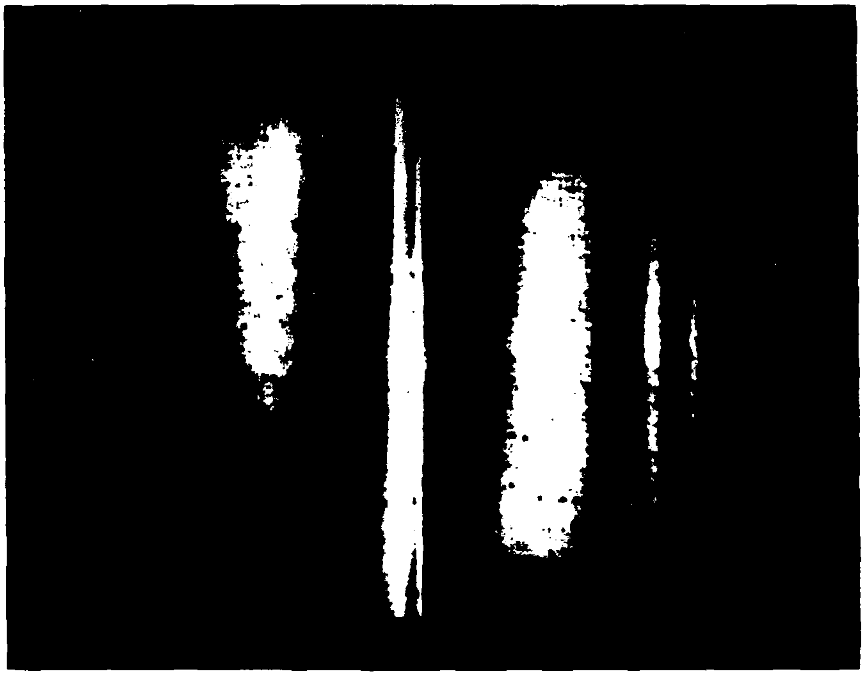


FIGURE 12: X-SHEAR INTERFEROGRAM (CURVED SIDE OF CYLINDER), WITH MIRROR OUT-OF-FOCUS AND ALIGNED

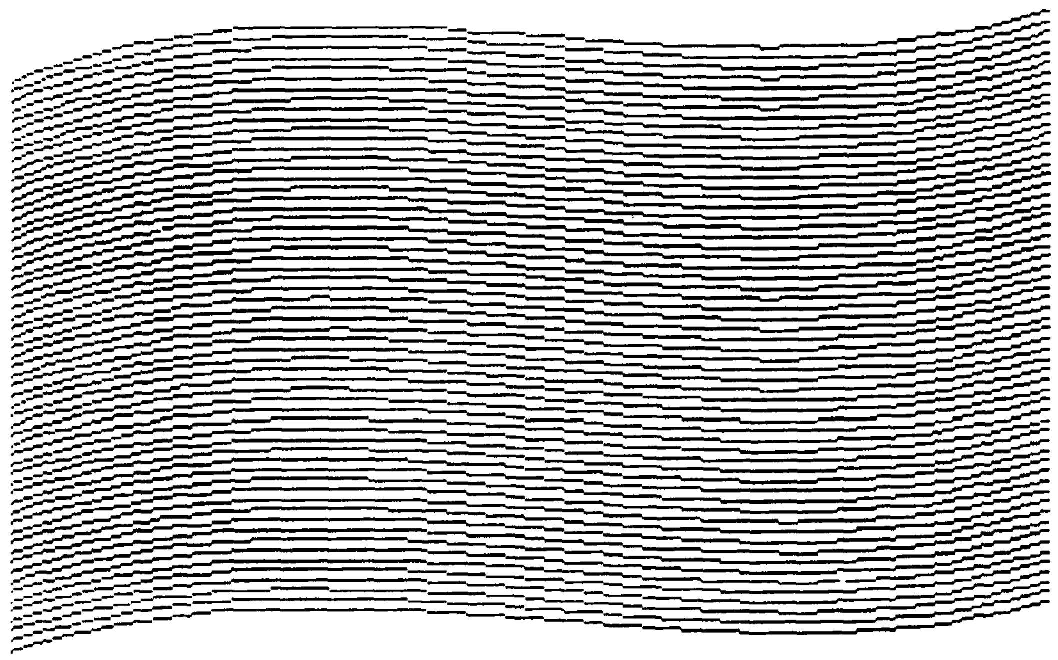
FIGURE 13: PHASE MEASUREMENT OF X-SHEAR INTERFEROGRAM (FIG. 12)

13-A: ORIGINAL, 3-D PLOT

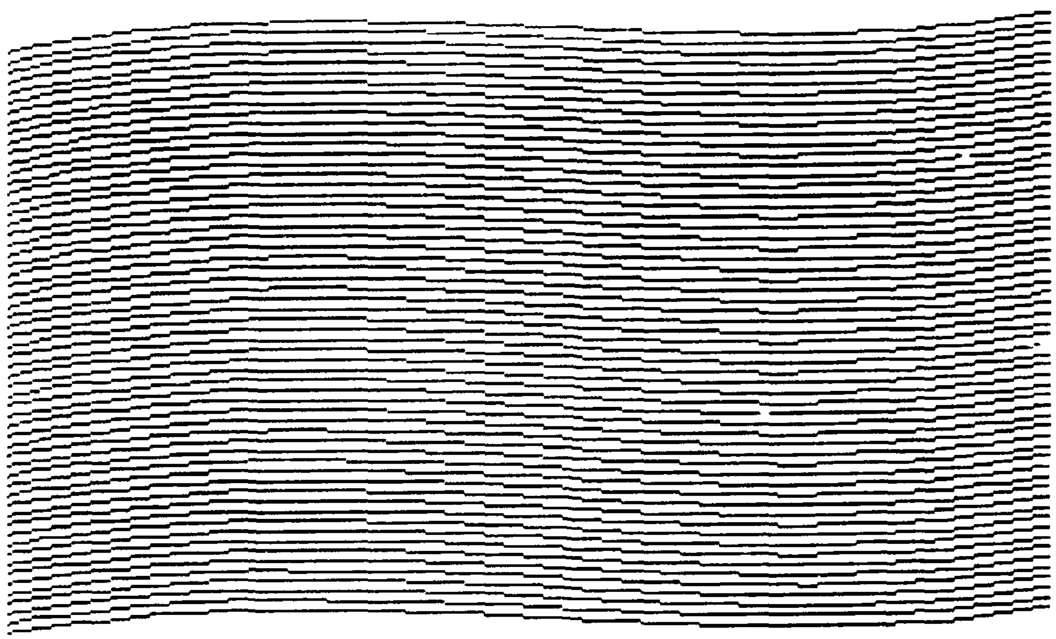
13-B: TILT REMOVED, 3-D PLOT

13-C: ORIGINAL, CONTOUR PLOT

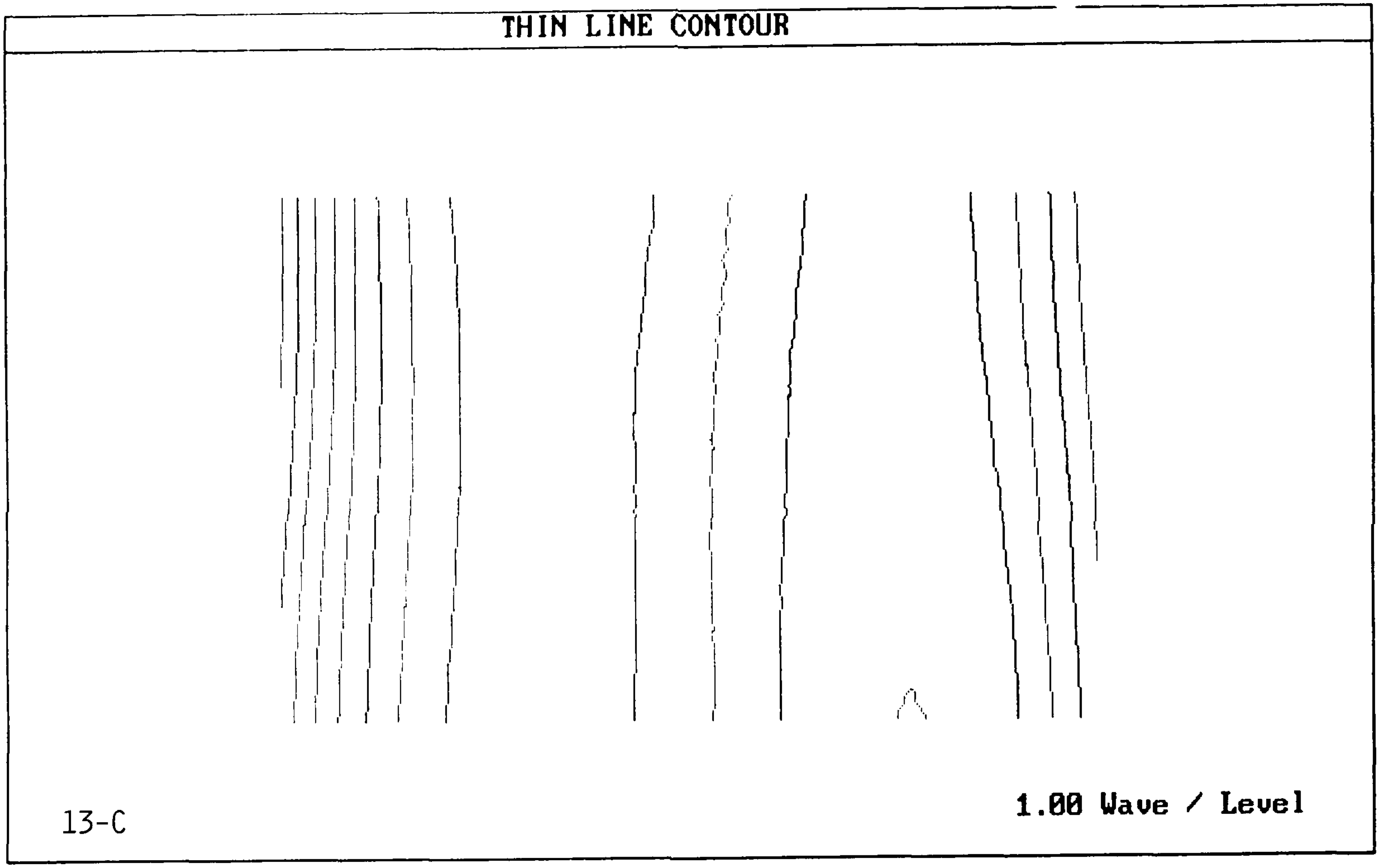
13-D: TILT REMOVED, CONTOUR PLOT

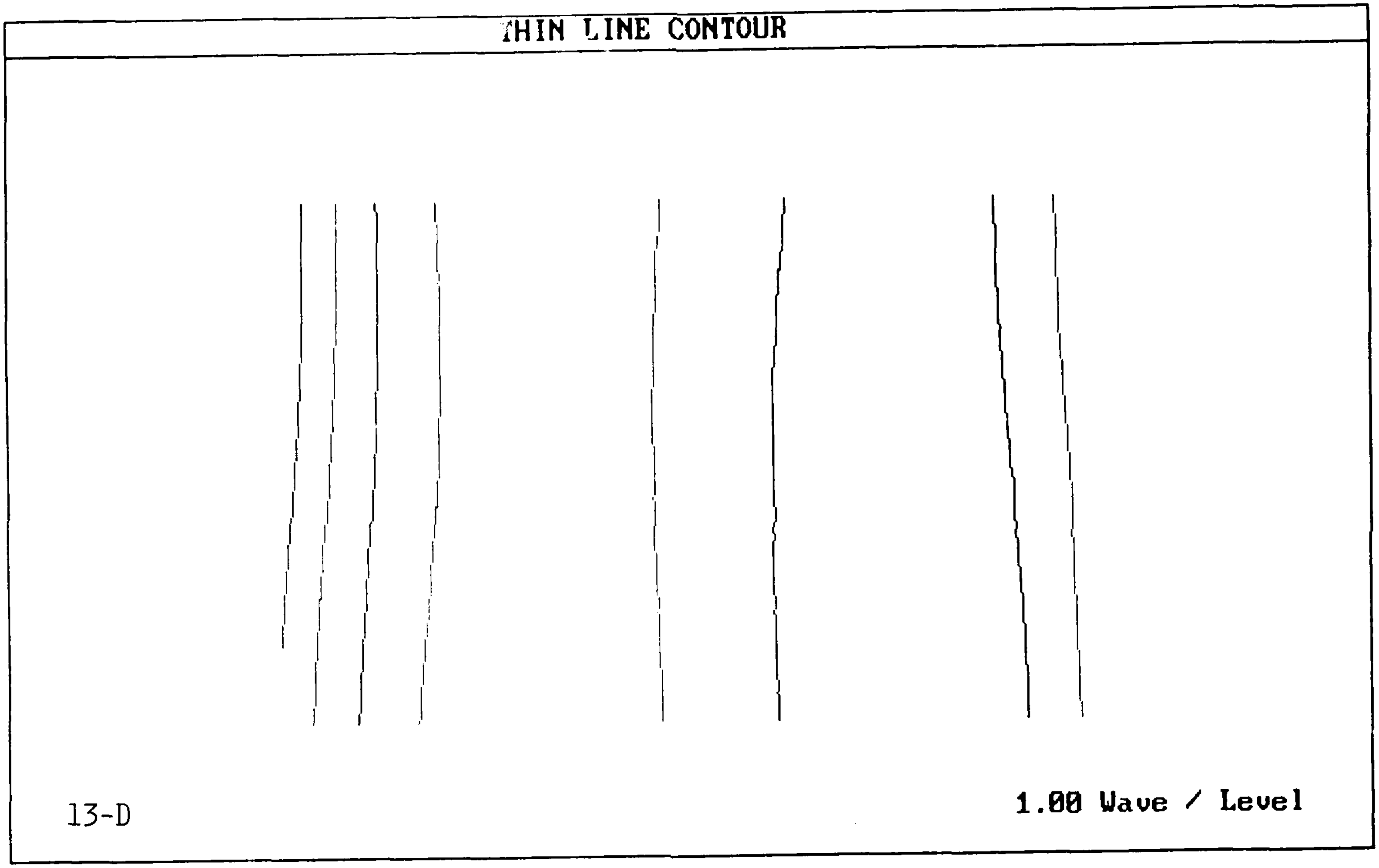


13-A



13-B


THIN LINE CONTOUR
13-C
1.00 Wave / Level


THIN LINE CONTOUR
13-D
1.00 Wave / Level

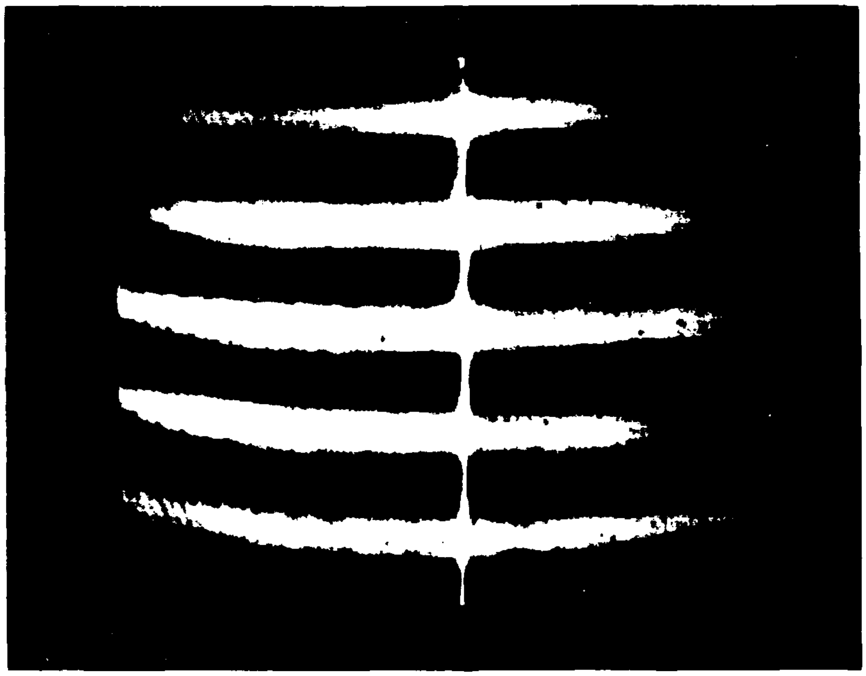


FIGURE 14: Y-SHEAR INTERFEROGRAM (STRAIGHT SIDE OF CYLINDER) WITH MIRROR OUT-OF-FOCUS AND ALIGNED

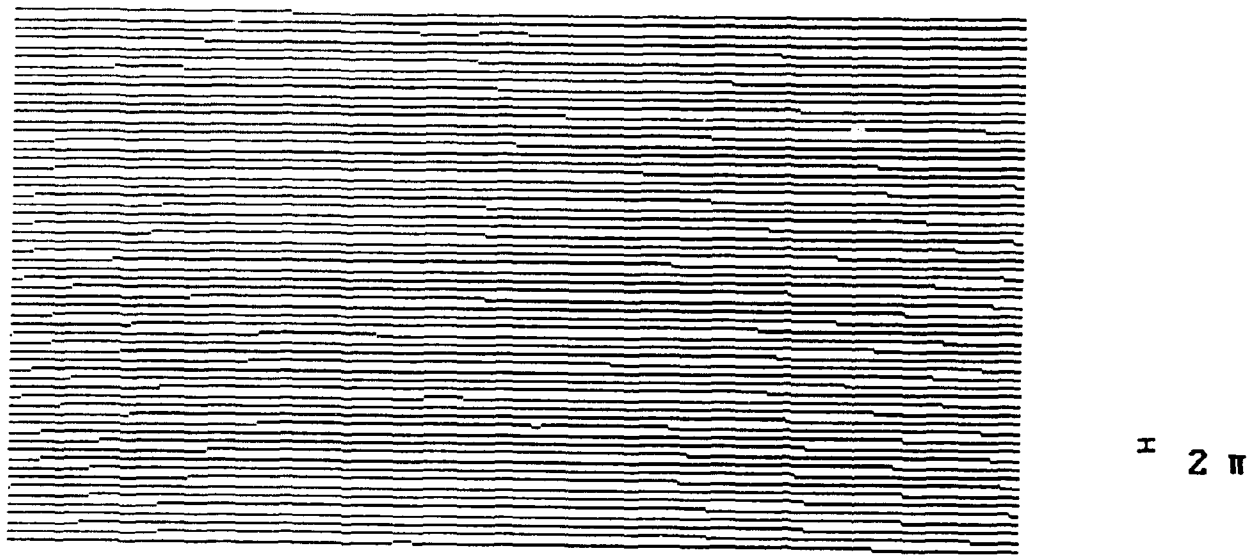
FIGURE 15: PHASE MEASUREMENT OF Y-SHEAR INTERFEROGRAM (FIG.14)

15-A: ORIGINAL, 3-D PLOT

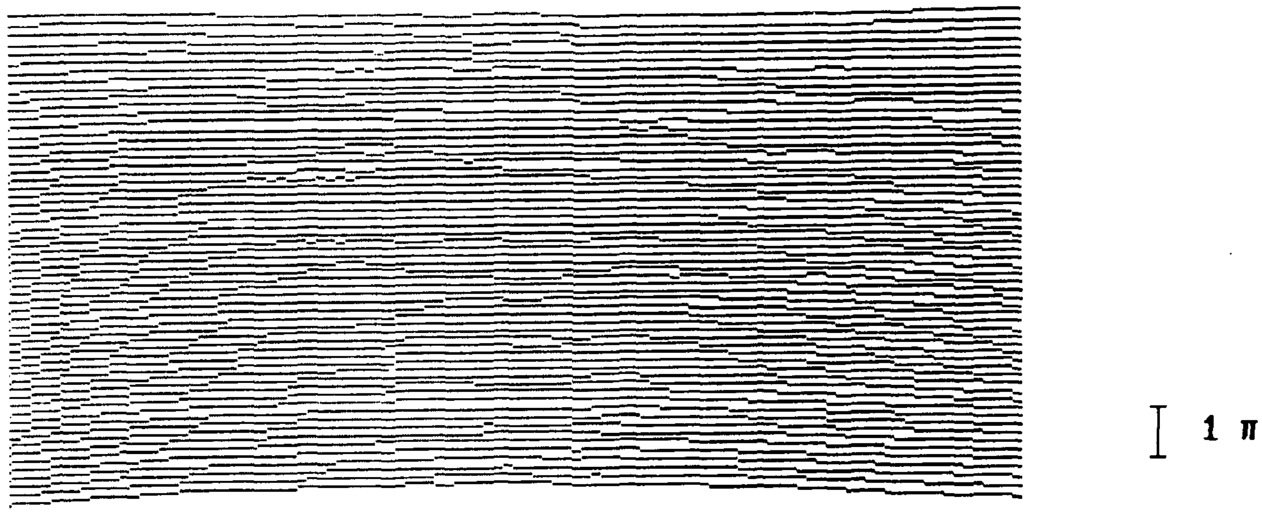
15-B: TILT REMOVED, 3-D PLOT

15-C: ORIGINAL, CONTOUR PLOT

15-D: TILT REMOVED, CONTOUR PLOT

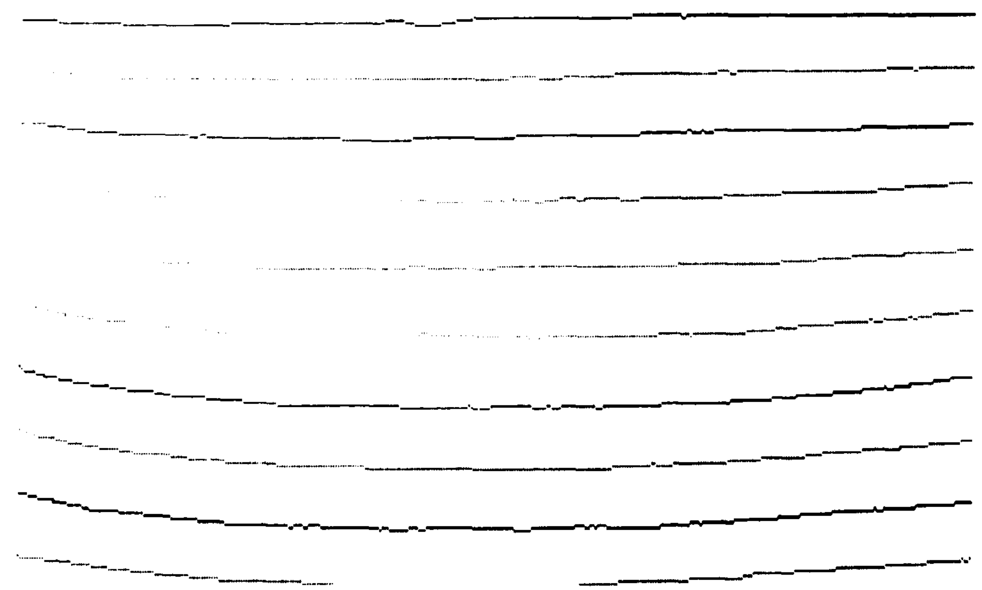


15-A



15-B

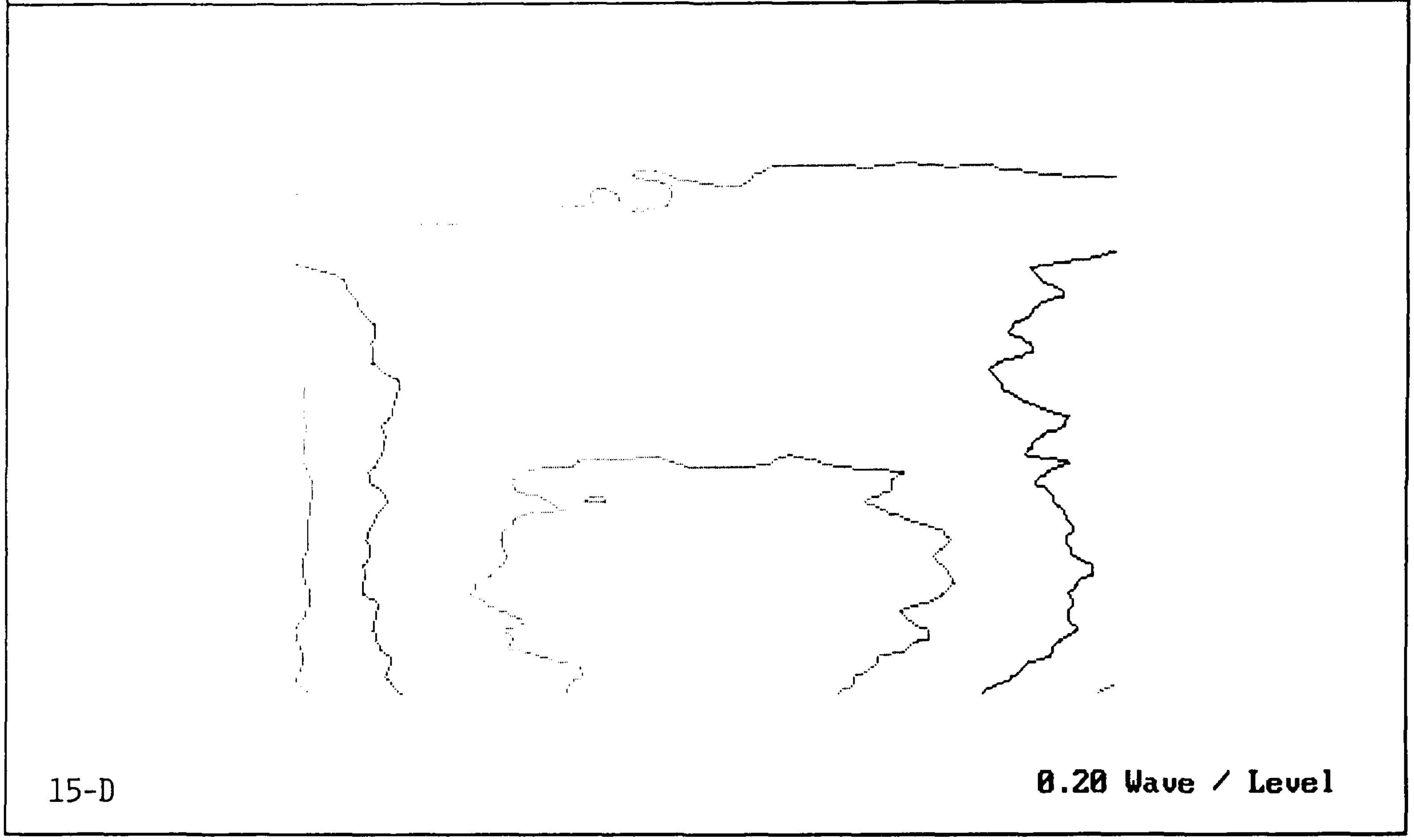
THIN LINE CONTOUR



15-C

1.00 Wave / Level

THIN LINE CONTOUR



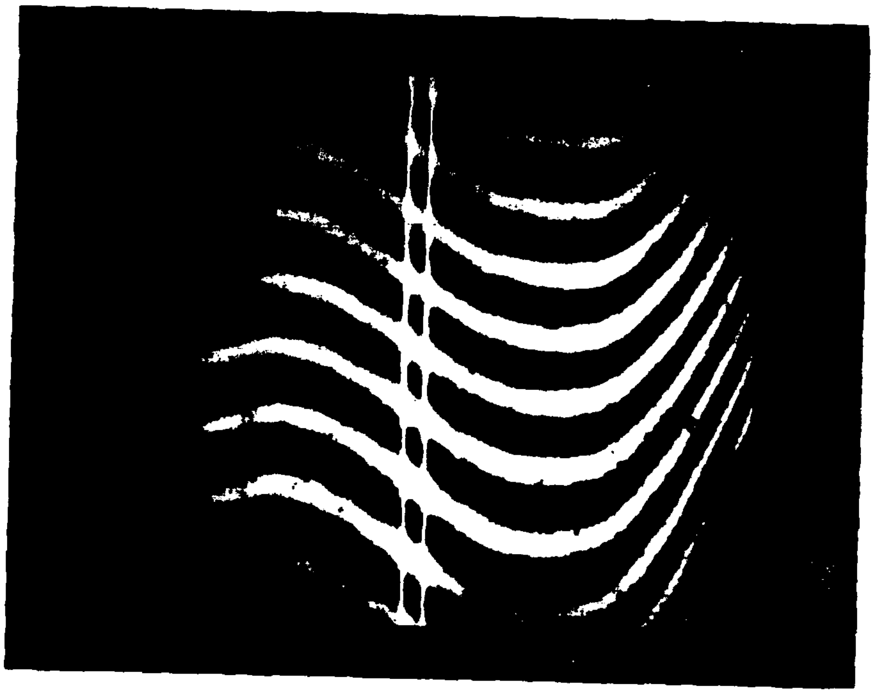


FIGURE 16: X-SHEAR INTERFEROGRAM (CURVED SIDE OF CYLINDER), WITH MIRROR OUT-OF-FOCUS AND MISALIGNED BY 1°

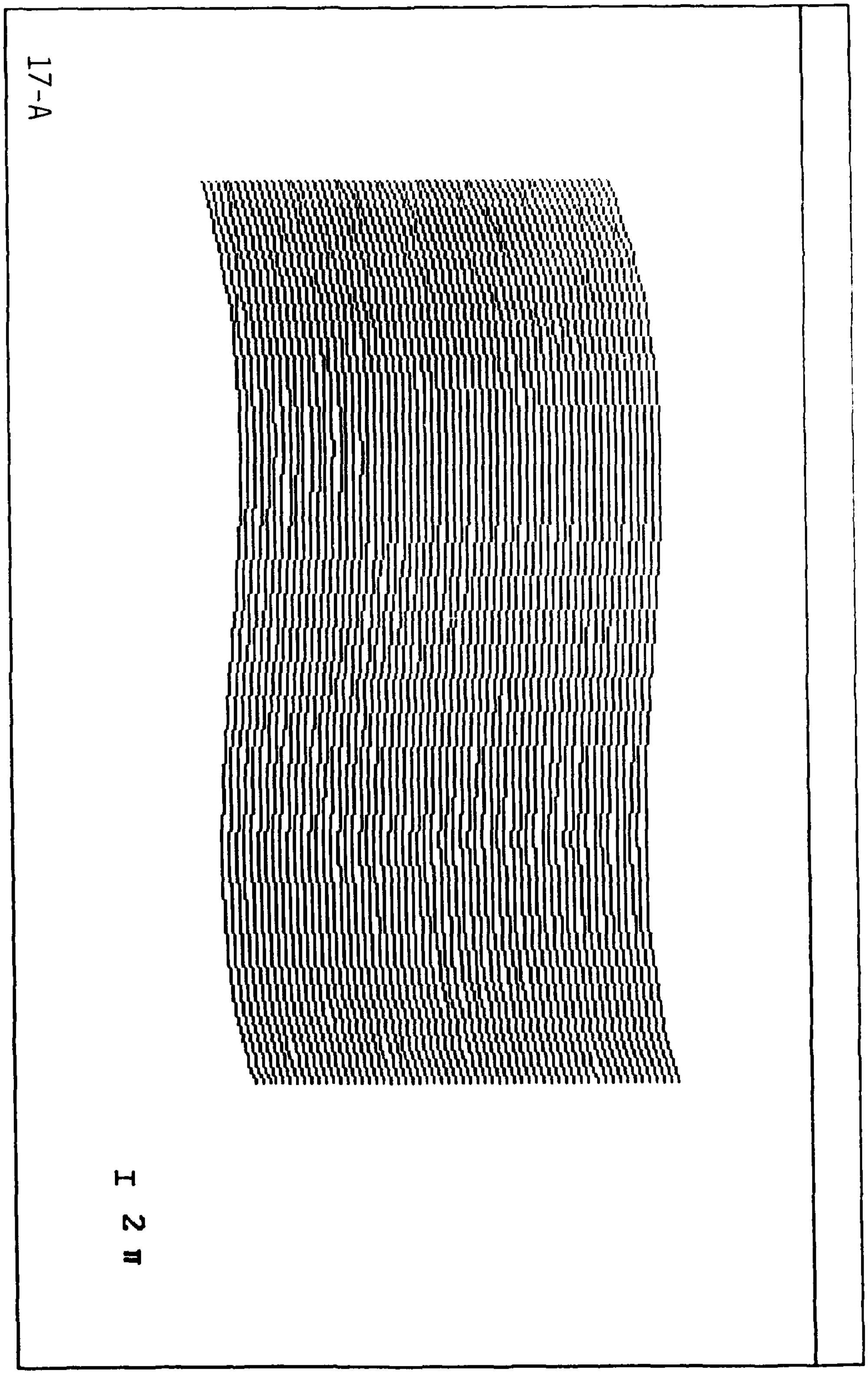
FIGURE 17: PHASE MEASUREMENT OF X-SHEAR INTERFEROGRAM (FIG.16)

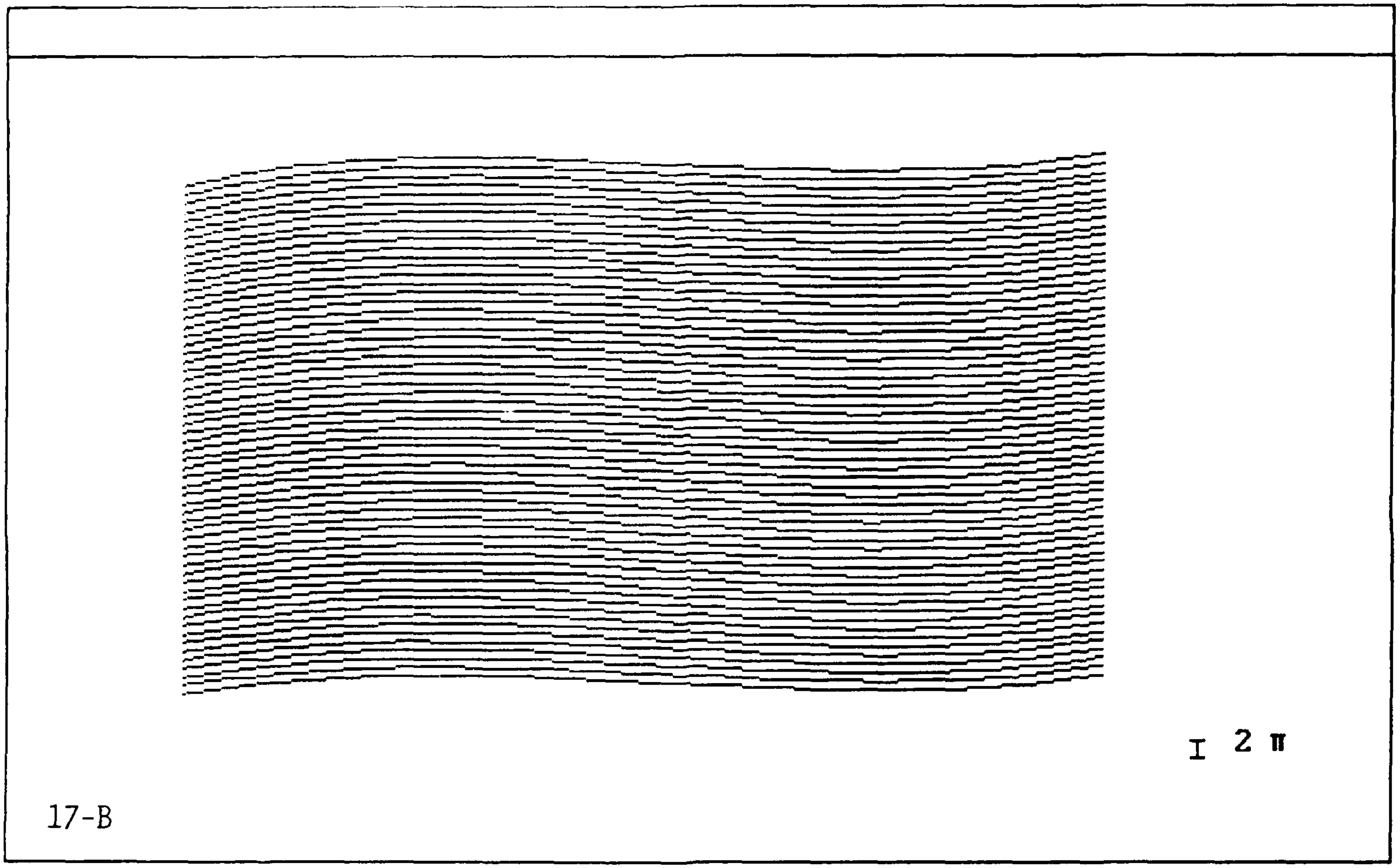
17-A: ORIGINAL, 3-D PLOT

17-B: TILT REMOVED, 3-D PLOT

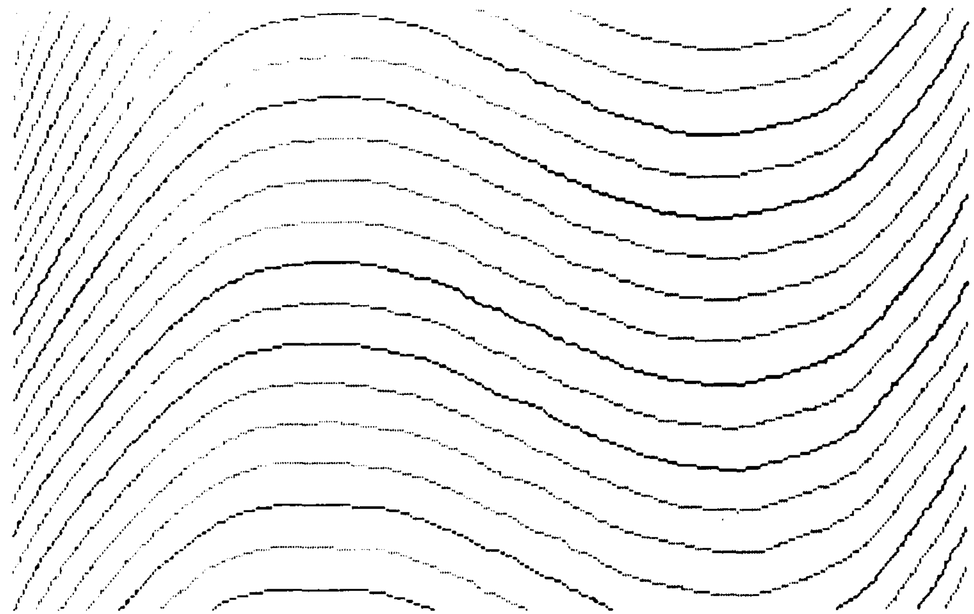
17-C: ORIGINAL, CONTOUR PLOT

17-D: TILT REMOVED, CONTOUR PLOT


17-A
I 2 π


I 2 π
17-B

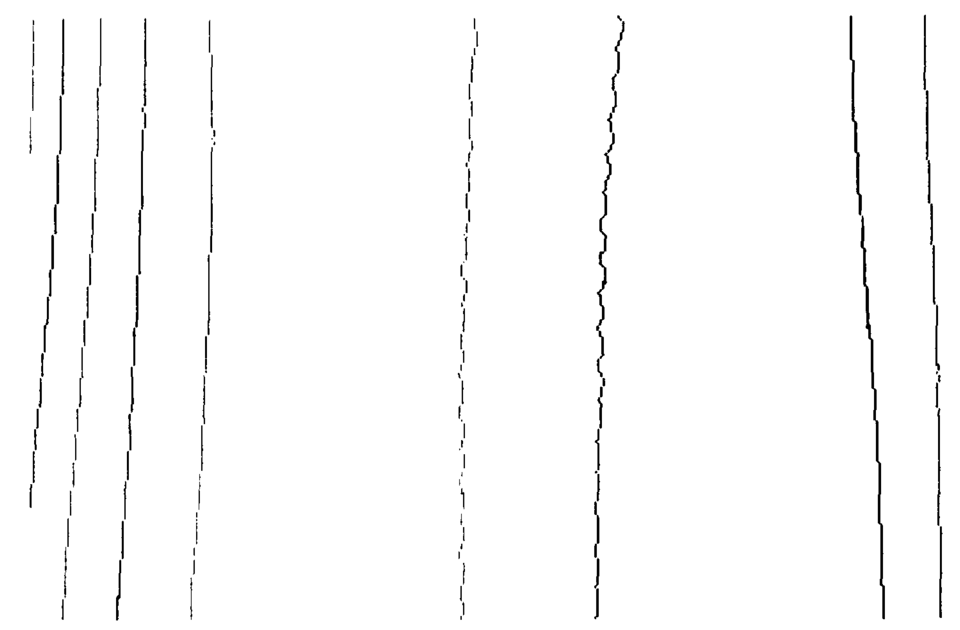
THIN LINE CONTOUR



17-C

1.00 Wave / Level

THIN LINE CONTOUR



17-D

1.00 Wave / Level

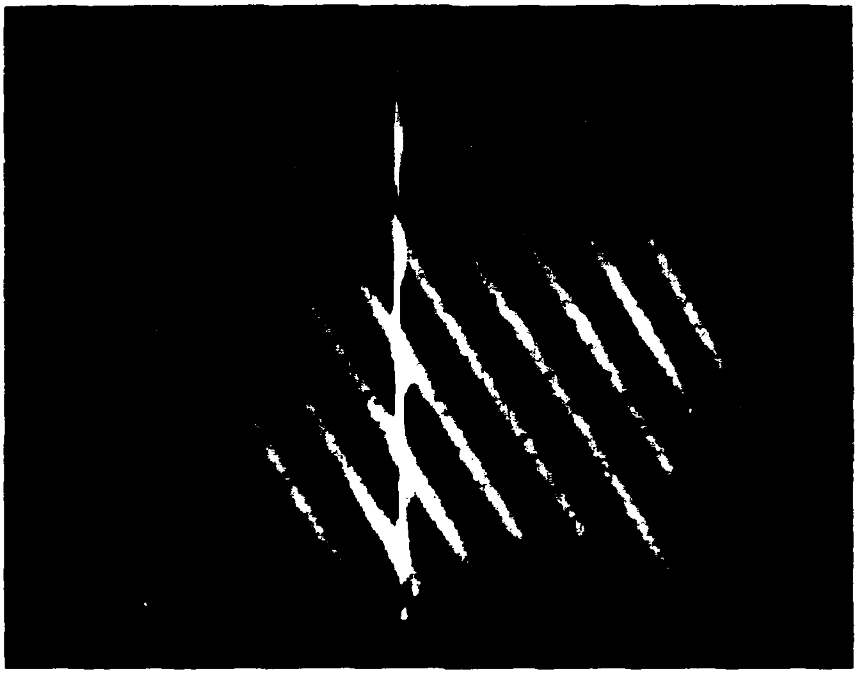


FIGURE 18: Y-SHEAR INTERFEROGRAM (STRAIGHT SIDE OF CYLINDER), WITH MIRROR OUT-OF-FOCUS AND MISALIGNED BY 1°

FIGURE 19: PHASE MEASUREMENT OF Y-SHEAR INTERFEROGRAM (FIG.18)

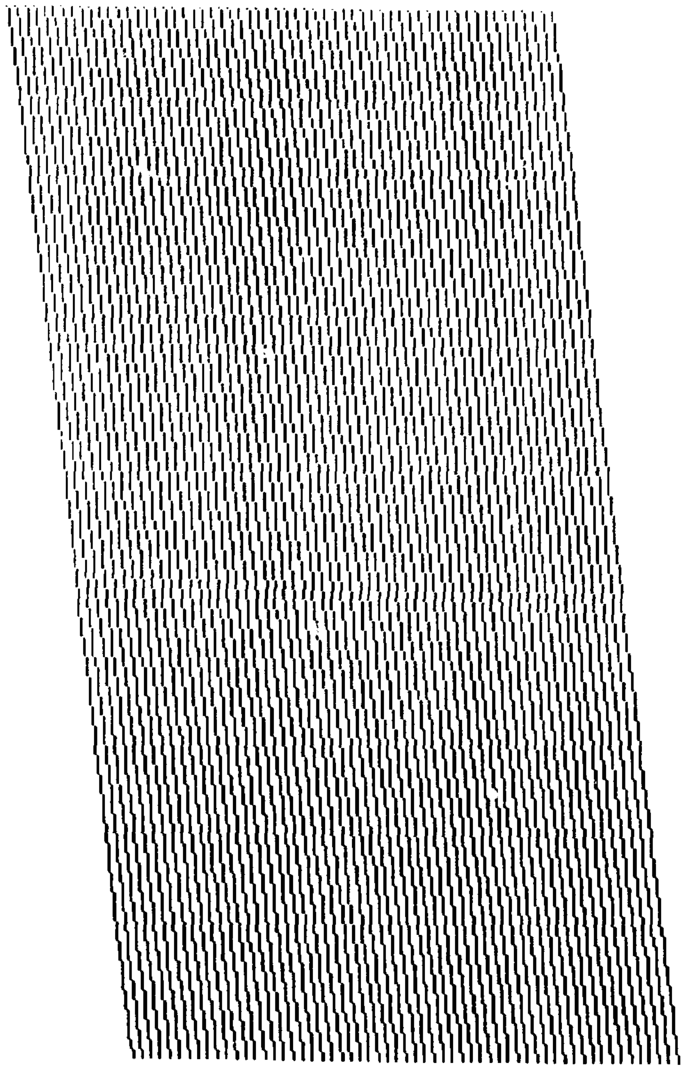
19-A: ORIGINAL, 3-D PLOT

19-B: TILT REMOVED, 3-D PLOT

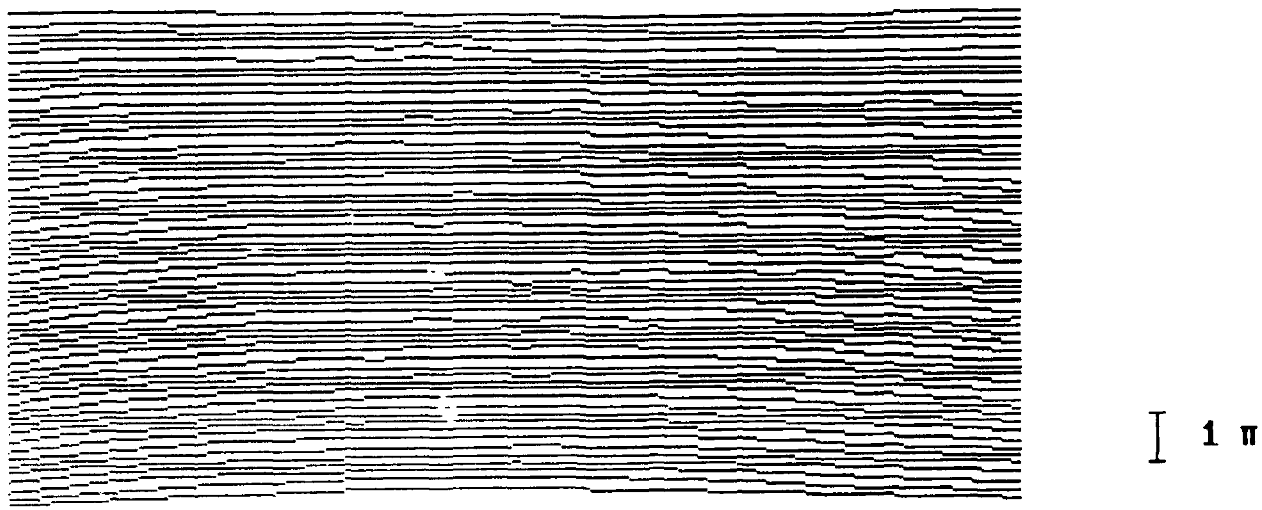
19-C: ORIGINAL, CONTOUR PLOT

19-D: TILT REMOVED, CONTOUR PLOT

19-A

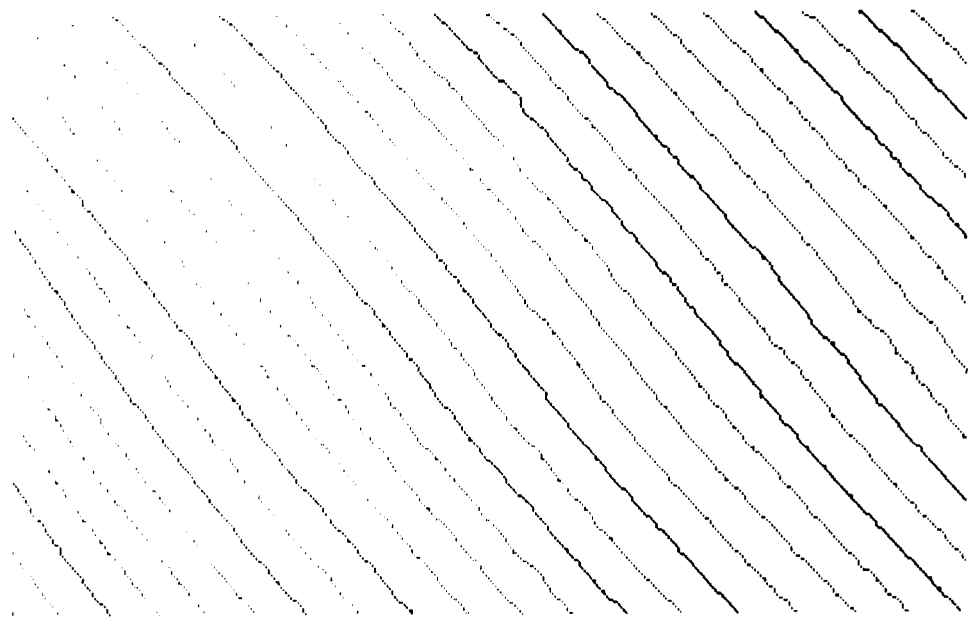


I 2 π



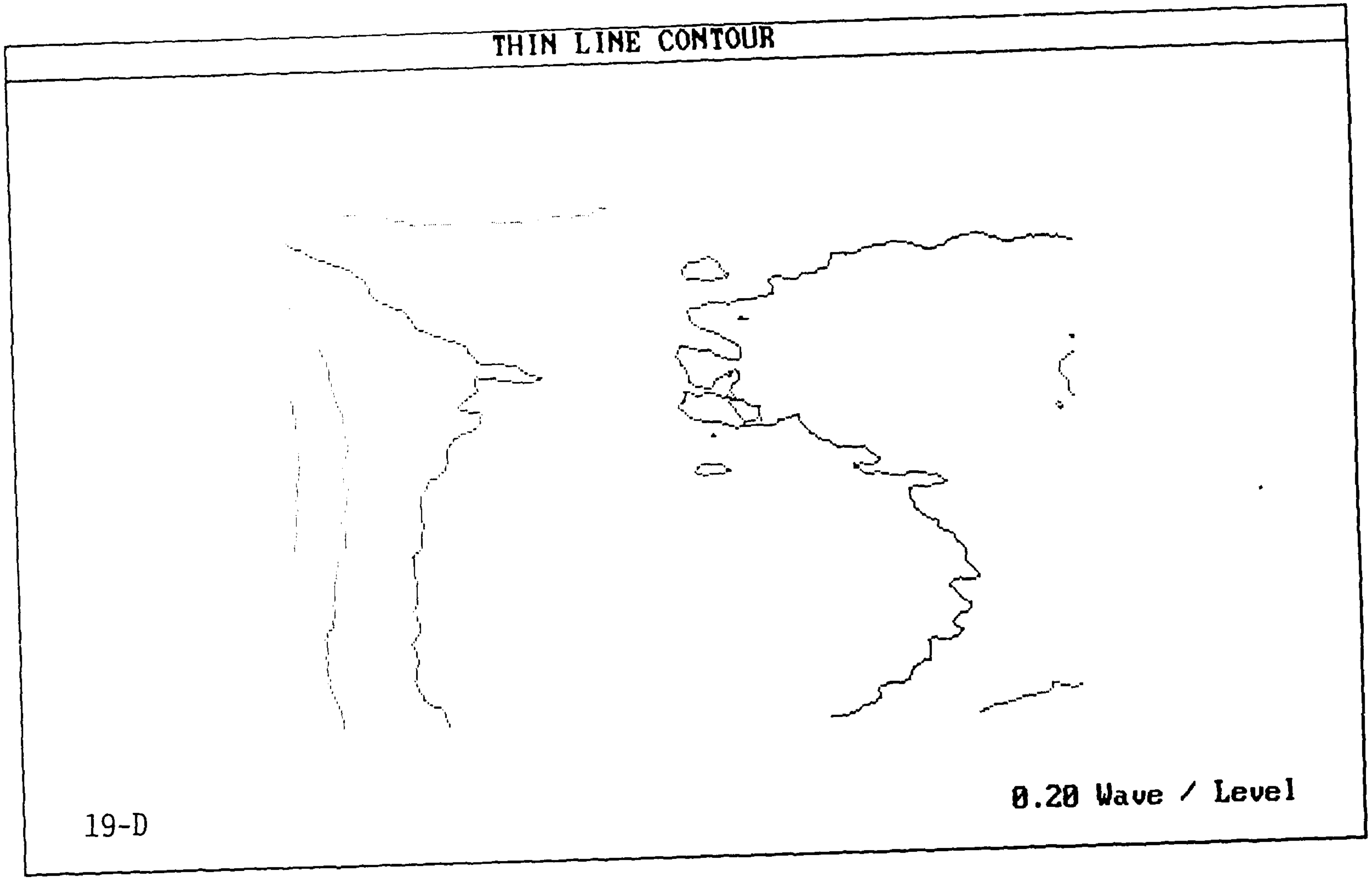
19-B

THIN LINE CONTOUR



19-C

1.00 Wave / Level


THIN LINE CONTOUR
0.20 Wave / Level
19-D

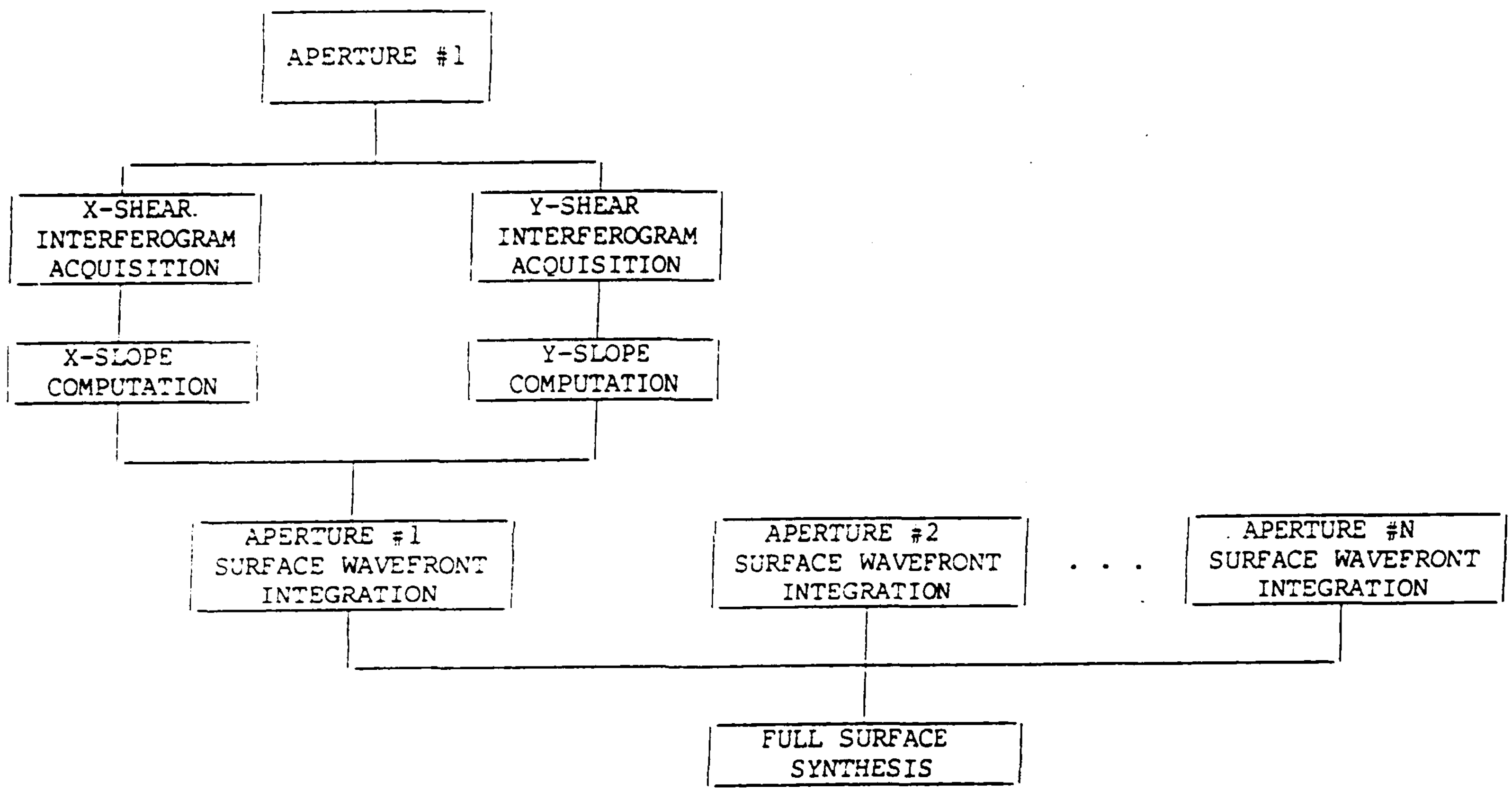
Software for Cylindrical surface Measurement

The source code software contained in this section was ~~specially~~ developed under this SDIO/ SBIR contract for use in the FSIS to carry out cylindrical surface measurement and describes the following processes:

1) Interferogram acquisition by means of the CCD camera.
2) Interferogram A/D conversion and storage on the frame buffer.
3) Fringe data processing to yield X and Y slope functions.
4) 3-D and contour displays.

The flow chart describing how the software processes data is given in figure 20.

The actual source code is contained on the next 11 pages after the flow chart.



Flow chart of preliminary software.

Figure 20

```
'***************************************
'*  CYLINDRICAL LENS MEASUREMENT PROGRAM *
'***************************************

'***************************************
' CONSTANTS AND VARIABLES AND ARRAYS
'***************************************

PI=3.141596
SIZE=240
STEPX=4
STEPY=4
DEGREE=180/PI
SCALE=5
DIM ORDER(SIZE),Y1(SIZE),X(SIZE),Y(SIZE),P(SIZE),IP(60,60)
DIM A(SIZE),B(SIZE),C(SIZE),D(SIZE),M(SIZE),M1(SIZE)

'***************************************
' ARRAYS FOR CONTOUR MAP
'***************************************

DIM SHARED  z(150)
DIM SHARED  h(4)
DIM SHARED  ish(4)
DIM SHARED  xh(4)
DIM SHARED  yh(4)
DIM SHARED  im(3)
DIM SHARED  jm(3)
DIM SHARED castab(2,2,2)
  im(0)=0 : im(1)=1 : im(2)=1 : im(3)=0
  jm(0)=0 : jm(1)=0 : jm(2)=1 : jm(3)=1
  for k=0 to 2
      for j=0 to 2
          for i=0 to 2
              read castab(k,j,i)
          next i
      next j
  next k
  data 0,0,8,0,2,5,7,6,9,0,3,4,1,0,1,4,3,0,9,6,7,5,2,0,8,0,0,0

SCREEN 9
CLS

'***************************************
' INTERFEROGRAM PARAMETER INPUTS
'***************************************

50 INPUT "FILE NAME1";NAME1$
   INPUT "FILE NAME2";NAME2$
   INPUT "LEFT BOUND";LEFT
   INPUT "RIGHT BOUND";RIGHT
   INPUT "TOP BOUND";TOP
   INPUT "BOTTOM BOUND";BOTTOM
   XC=INT(RIGHT-LEFT)/2
   YC=INT(RIGHT-LEFT)/2

   IF STEPY<3 THEN
   PRINT "PLEASE ENTER STEP Y > 3"
   GOTO 50
   END IF
   IF LEN(NAME1$)>7 THEN
   PRINT "PLEASE ENTER FILE NAME LENGTH < 8"
   GOTO 50
   END IF
   IF LEN(NAME2$)>7 THEN
```

```
   PRINT "PLEASE ENTER FILE NAME LENGTH < 8"
   GOTO 50
   END IF
   IF LEFT<1  THEN
   PRINT "PLEASE ENTER LEFT BOUNDARY > 0 "
   GOTO 50
   END IF
   IF RIGHT>SIZE  THEN
   PRINT "PLEASE ENTER RIGHT BOUNDARY <"SIZE
   GOTO 50
   END IF
   IF TOP<1 THEN
   PRINT "PLEASE ENTER TOP BOUNDARY < 1"
   GOTO 50
   END IF
   IF BOTTOM>240  THEN
   PRINT "PLEASE ENTER BOTTOM BOUNDARY < 240
   GOTO 50
   END IF

'****************************************
' SETUP IMAGE BUFFER PARAMETERS
'****************************************

    OPEN "LOAD2V" FOR OUTPUT AS #1
    PRINT #1,"L S I"
    PRINT #1,"P X "SIZE;" 3 60 I N V 1 Q E P Q"
    PRINT #1,"P D N Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"1.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"1.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"2.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"3.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"4.DAT Q"
    PRINT #1,"QU"
    CLOSE #1

'****************************************
' CONTROL IMAGE BUFFER AND ACQUIRE IMAGES
'****************************************

    INPUT "DATA LOADED IN BUFFER (Y/N)";Y$
    IF Y$="n" OR Y$="N" THEN
       SHELL "LOAD2V.BAT"
       CLS
    END IF

'****************************************
' OPEN IMAGE #1 SET INPUT/OUTPUT FILES
'****************************************

P1$=NAME1$+"1.DAT"
P2$=NAME1$+"2.DAT"
P3$=NAME1$+"3.DAT"
P4$=NAME1$+"4.DAT"

OPEN P1$ AS #1 LEN=SIZE
OPEN P2$ AS #2 LEN=SIZE
OPEN P3$ AS #3 LEN=SIZE
OPEN P4$ AS #4 LEN=SIZE

FIELD #1,SIZE AS A$
FIELD #2,SIZE AS B$
FIELD #3,SIZE AS C$
FIELD #4,SIZE AS D$
```

```
'****************************************
' COMPUTE CENTER COLUMN LINE DATA
'****************************************

FOR I=BOTTOM TO TOP STEP -1
       GET #1,I
       GET #2,I
       GET #3,I
       GET #4,I
       E$=MID$(A$,YC,1)
       F$=MID$(B$,YC,1)
       G$=MID$(C$,YC,1)
       H$=MID$(D$,YC,1)
       A=ASC(E$)
       B=ASC(F$)
       C=ASC(G$)
       D=ASC(H$)
       AN=B-D
       DEN=A-C
       IF DEN=0 THEN DEN=0.0001
       T=ABS(AN/DEN)
       P=ATN(T)*DEGREE
       IF DEN<0 THEN 100
       IF AN<0 THEN P=360-P:GOTO 200
       GOTO 200
100    IF AN<0 THEN P=P+180:GOTO 200
       P=180-P
200    P(I)=P
       ORDER(I)=0
NEXT I

'****************************************
' ASSIGN THE INTERFEROGRAM FRINGE ORDERS
'****************************************

C=0
FOR I=YC TO BOTTOM
    IF P(I+1)-P(I)<-180 THEN C=C+1
    IF P(I+1)-P(I)>180 THEN C=C-1
    ORDER(I+1)=C
NEXT I

FOR I=YC TO TOP STEP -1
    IF I=YC THEN GOTO 300
    IF P(I+1)-P(I)<-180 THEN C=C-1
    IF P(I+1)-P(I)>180 THEN C=C+1
300 ORDER(I)=C
NEXT I

'****************************************
' COMPUTE ROW LINE DATA AND DISPLAY
'****************************************

ICOUNT=0
FOR I=TOP TO BOTTOM STEP STEPY
       ICOUNT=ICOUNT+1
       GET #1,I
       GET #2,I
       GET #3,I
       GET #4,I
       FOR J=LEFT TO RIGHT
          E$=MID$(A$,J,1)
          F$=MID$(B$,J,1)
          G$=MID$(C$,J,1)
          H$=MID$(D$,J,1)
```

```
            A(J)=ASC(E$)
            B(J)=ASC(F$)
            C(J)=ASC(G$)
            D(J)=ASC(H$)
         NEXT J
         FOR J=LEFT TO RIGHT
            AN=B-D
            DEN=A-C
            IF DEN=0 THEN DEN=0.0001
            T=ABS(AN/DEN)
            P=ATN(T)*DEGREE
            IF DEN<0 THEN 400
            IF AN<0 THEN P=360-P:GOTO 500
            GOTO 500
400         IF AN<0 THEN P=P+180:GOTO 500
            P=180-P
500         P(J)=P
         NEXT J

'****************************************
' ASSIGN THE INTERFEROGRAM FRINGE ORDERS
'****************************************

         C=ORDER(I)
         FOR J=XC TO RIGHT
            IF P(J+1)-P(J)<-180 THEN C=C+1
            IF P(J+1)-P(J)>180 THEN C=C-1
            Y1(J+1)=P(J+1)+C*360
         NEXT J
         C=ORDER(I)
         FOR J=XC TO LEFT STEP -1
            IF P(J+1)-P(J)<-180 THEN C=C-1
            IF P(J+1)-P(J)>180 THEN C=C+1
            Y1(J)=P(J)+C*360
         NEXT J

'****************************************
' DISPLAY THE INTERFEROGRAM DATA
'****************************************

         FOR J=LEFT TO RIGHT
            X2=J*1.5+(I-TOP)/2
            Y2=Y1(J)/SCALE
            IF J MOD STEPX THEN IP(ICOUNT,INT(J/4))=Y1(J)
            Y2=-Y2+120-(I-TOP)/2
            IF I=I1 THEN GOTO 700
            IF J=J1 THEN GOTO 1000
            GOSUB 10000
            GOTO 1000
700         M1(J)=Y2
            IF J=J1 THEN GOTO 1000
            LINE (X1,Y1)-(X2,Y2)
1000        X1=X2:Y1=Y2
      NEXT J
            FOR J=LEFT TO RIGHT
               J0=J+(I-TOP)/4
               M(J0)=M1(J0)
            NEXT J
            M(J2+1+(I-I1)/4)=200

NEXT I
1500 Y$=INKEY$:IF Y$="" THEN GOTO 1500

'***************************************
' DISPLAY CONTOUR MAP OF INTERFEROGRAM
```

```
'************************************

GOSUB 20000
CLS
CLOSE

'*****************************************
' SETUP IMAGE BUFFER PARAMETERS
'*****************************************

    OPEN "LOAD2V" FOR OUTPUT AS #1
    PRINT #1,"L S I"
    PRINT #1,"P X "SIZE;" 3 60 I N V 1 Q E P Q"
    PRINT #1,"P D N Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"1.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"1.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"2.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"3.DAT Q"
    PRINT #1,"M B 1 Q F R "NAME1$+"4.DAT Q"
    PRINT #1,"QU"
    CLOSE #1

'*****************************************
' CONTROL IMAGE BUFFER AND ACQUIRE IMAGES
'*****************************************

    INPUT "DATA LOADED IN BUFFER (Y/N)";Y$
    IF Y$="n" OR Y$="N" THEN
       SHELL "LOAD2V.BAT"
       CLS
    END IF


'*****************************************
' OPEN IMAGE #2 SET INPUT/OUTPUT FILES
'*****************************************

P1$=NAME2$+"1.DAT"
P2$=NAME2$+"2.DAT"
P3$=NAME2$+"3.DAT"
P4$=NAME2$+"4.DAT"

OPEN P1$ AS #1 LEN=SIZE
OPEN P2$ AS #2 LEN=SIZE
OPEN P3$ AS #3 LEN=SIZE
OPEN P4$ AS #4 LEN=SIZE

FIELD #1,SIZE AS A$
FIELD #2,SIZE AS B$
FIELD #3,SIZE AS C$
FIELD #4,SIZE AS D$

'*****************************************
' COMPUTE CENTER COLUMN LINE DATA
'*****************************************

FOR I=BOTTOM TO TOP STEP -1
       GET #1,I
       GET #2,I
       GET #3,I
       GET #4,I
       E$=MID$(A$,YC,1)
       F$=MID$(B$,YC,1)
       G$=MID$(C$,YC,1)
       H$=MID$(D$,YC,1)
```

```
        A=ASC(E$)
        B=ASC(F$)
        C=ASC(G$)
        D=ASC(H$)
        AN=B-D
        DEN=A-C
        IF DEN=0 THEN DEN=0.0001
        T=ABS(AN/DEN)
        P=ATN(T)*DEGREE
        IF DEN<0 THEN 2100
        IF AN<0 THEN P=360-P:GOTO 2200
        GOTO 2200
2100     IF AN<0 THEN P=P+180:GOTO 2200
        P=180-P
2200     P(I)=P
        ORDER(I)=0
NEXT I

'****************************************
' ASSIGN THE INTERFEROGRAM FRINGE ORDERS
'****************************************

C=0
FOR I=YC TO BOTTOM
    IF P(I+1)-P(I)<-180 THEN C=C+1
    IF P(I+1)-P(I)>180 THEN C=C-1
    ORDER(I+1)=C
NEXT I

FOR I=YC TO TOP STEP -1
    IF I=YC THEN GOTO 2300
    IF P(I+1)-P(I)<-180 THEN C=C-1
    IF P(I+1)-P(I)>180 THEN C=C+1
2300 ORDER(I)=C
NEXT I

'****************************************
' COMPUTE ROW LINE DATA AND DISPLAY
'****************************************

ICOUNT=0
FOR I=TOP TO BOTTOM STEP STEPY
       ICOUNT=ICOUNT+1
       GET #1,I
       GET #2,I
       GET #3,I
       GET #4,I
       FOR J=LEFT TO RIGHT
          E$=MID$(A$,J,1)
          F$=MID$(B$,J,1)
          G$=MID$(C$,J,1)
          H$=MID$(D$,J,1)
          A(J)=ASC(E$)
          B(J)=ASC(F$)
          C(J)=ASC(G$)
          D(J)=ASC(H$)
       NEXT J
       FOR J=LEFT TO RIGHT
          AN=B-D
          DEN=A-C
          IF DEN=0 THEN DEN=0.0001
          T=ABS(AN/DEN)
          P=ATN(T)*DEGREE
          IF DEN<0 THEN 2400
          IF AN<0 THEN P=360-P:GOTO 2500
```

```
        GOTO 2500
2400     IF AN<0 THEN P=P+180:GOTO 2500
        P=180-P
2500     P(J)=P
      NEXT J

'****************************************
' ASSIGN THE INTERFEROGRAM FRINGE ORDERS
'****************************************

      C=ORDER(I)
      FOR J=XC TO RIGHT
         IF P(J+1)-P(J)<-180 THEN C=C+1
         IF P(J+1)-P(J)>180 THEN C=C-1
         Y1(J+1)=P(J+1)+C*360
      NEXT J
      C=ORDER(I)
      FOR J=XC TO LEFT STEP -1
         IF P(J+1)-P(J)<-180 THEN C=C-1
         IF P(J+1)-P(J)>180 THEN C=C+1
         Y1(J)=P(J)+C*360
      NEXT J
'****************************************
' DISPLAY THE INTERFEROGRAM DATA
'****************************************
      FOR J=LEFT TO RIGHT
         X2=J*1.5+(I-TOP)/2
         Y2=Y1(J)/SCALE
         IF J MOD STEPX THEN IP(ICOUNT,INT(J/4))=Y1(J)
         Y2=-Y2+120-(I-TOP)/2
         IF I=I1 THEN GOTO 2700
         IF J=J1 THEN GOTO 3000
         GOSUB 10000
         GOTO 3000
2700     M1(J)=Y2
         IF J=J1 THEN GOTO 3000
         LINE (X1,Y1)-(X2,Y2)
3000     X1=X2:Y1=Y2
     NEXT J
         FOR J=LEFT TO RIGHT
            J0=J+(I-TOP)/4
            M(J0)=M1(J0)
         NEXT J
         M(J2+1+(I-I1)/4)=200
NEXT I
3500 Y$=INKEY$:IF Y$="" THEN GOTO 3500

'**************************************
' DISPLAY CONTOUR MAP OF INTERFEROGRAM
'**************************************

GOSUB 20000
CLS
CLOSE
END



10000
'******************************
' SUB PROGRAM OF HIDDEN LINE
'******************************

      J0=J+(I-TOP)/4
      IF Y1<M(J0) THEN 10100
```

```
      IF J=J2 THEN 10050
      IF Y2=M(J0+1) THEN 10200
      RETURN
10050 M1(J0+1)=Y2
      LINE (X1,Y1)-(X2,Y2)
      RETURN
10100 IF J=J2 THEN 10100
      IF Y2<M(J0+1) THEN 10200
      GOTO 10150
      M1(J0)=Y1
      M1(J0+1)=Y2
      LINE (X1,Y1)-(X2,Y2)
10150 M=(Y2-Y1)/(X2-X1)
      B=Y1-M*X1
      D=((Y1-M(J0))*(X2-X1))/(M(J0+1)-Y2+Y1-M(J0))
      X=X1+D
      Y=M*X+B
      LINE (X1,Y1)-(X,Y)
      M1(J0)=Y1
      RETURN
10200 M=(Y1-Y2)/(X1-X2)
      B=Y1-M*X1
      D=((M(J0)-Y1)*(X2-X1))/(Y2-M(J0+1)+M(J0)-Y1)
      X=X1+D
      Y=M*X+B
      LINE (X,Y)-(X2,Y2)
      M1(J0+1)=Y2
      RETURN


20000
'************************************************
' SUBROUTINE DISPLAY CONTOUR MAP OF INTERFEROGRAM
'************************************************

    xdim=150
    coldim=150
    xn=60
    yn=60
    stepno=4
    xf=left
    yf=top
    xs=stepx
    ys=stepy
    xsp=100
    ysp=50
    redim x(xdim)
    redim y(xdim)
    redim colors(coldim)

'   IP(2)    : z-value array
'   xf       : start value of x-direction index
'   yf       : start value of y-direction index
'   xn       : # of point in x-direction
'   yn       : # of ponit in y-direction
'   stpno    : step no
'   xs       : x-scale
'   ys       : y-scale
'   xsp      : start position of x-direction
'   ysp      : start position of y-direction

for i = 1 to xn
    x(i) = xsp + (i - 1) * xs
    next i
for i = 1 to yn
```

```
    y(i) = ysp + (i - 1) * ys
    next i

mm = (xn - xf) mod stpno
xe = xn - mm - stpno
mm = (yn - yf) mod stpno
ye = yn - mm - stpno

if min <= 0 and max >= 0 then
   exlevel = 1
  else
   exlevel = 0
   end if
'******** main process ********

mainp:
if que$ = "y" then
   input "line contour step(wave):";stepcon
   yrow=4:xcol=25
   end if
if stepcon=0 then goto 10202
zma = abs(max) / (360*stepcon)
zmi = abs(min) / (360*stepcon)
zma = int(zma)
zmi = int(zmi)
mmi = min mod (360*stepcon)
mma = max mod (360*stepcon)
level1 = zma + zmi
level = level1 + exlevel
if min > 0 and min < (360*stepcon) then
   for i = 0 to level - 1
       z(i) = min - mmi + (i + 1) * (360*stepcon)
       colors(i)=i mod 16
       next i
  else
   for i = 0 to level - 1
       z(i) = min - mmi + i * (360*stepcon)
       colors(i)=i mod 16
       next i
   end if
      locate 6,xmm: print cmd$
      locate yrow%+2,xcol%:print "STEP:"stepcon
   for j=ye to yf step -stpno
    if j<=top or j=>bottom then goto noneinbox
    for i=xf to xe step stpno
        if i<LEFT or i>RIGHT then goto noneinbox
        if (IP(i,j)<IP(i,j+stpno)) then
           dmin=IP(i,j)
        else
           dmin=IP(i,j+stpno)
        end if
        if IP(i+stpno,j)<dmin then dmin=IP(i+stpno,j)
        if IP(i+stpno,j+stpno)<dmin then dmin=IP(i+stpno,j+stpno)
        if IP(i,j)>IP(i,j+stpno) then
           dmax=IP(i,j)
        else
           dmax=IP(i,j+stpno)
        end if
        if IP(i+stpno,j)>dmax then dmax=IP(i+stpno,j)
        if IP(i+stpno,j+stpno)>dmax then dmax=IP(i+stpno,j+stpno)
        if dmax<z(0) or dmin>z(level-1) then goto noneinbox
        for k=0 to level - 1
            if z(k)<dmin or z(k)>dmax then goto noneintri
            for m=4 to 0 step -1
```

```
            if m>0 then
               h(m)=IP(i+stpno*im(m-1),j+stpno*jm(m-1))-z(k)
               xh(m)=x(i+stpno*im(m-1))
               yh(m)=y(j+stpno*jm(m-1))
            end if
            if m=0 then
               h(0)=(h(1)+h(2)+h(3)+h(4))/4
               xh(0)=(x(i)+x(i+stpno))/2
               yh(0)=(y(j)+y(j+stpno))/2
            end if
            if h(m)>0 then
               ish(m)=2
            elseif (h(m)<0) then
               ish(m)=0
            else
               ish(m)=1
            end if
        next m
        swskip$ = "n"
        for m=1 to 4
            if swskip$ = "y" then
               swskip$ = "n"
               go to case0
               end if
            m1=m:m2=0:m3=m+1
            if m3=5 then m3=1
            casetype=cint(castab(ish(m1),ish(m2),ish(m3)))
            if casetype=0 then
               swskip$ = "n"
               goto case0
               end if
on casetype goto case1,case2,case3,case4,case5,case6,case7,case8,case9
            case1:
                 x1=xh(m1):y1=yh(m1):x2=xh(m2):y2=yh(m2)
                 goto drawit
            case2:
                 x1=xh(m2):y1=yh(m2):x2=xh(m3):y2=yh(m3)
                 swskip$ = "y"
                 goto drawit
            case3:
                 x1=xh(m3):y1=yh(m3):x2=xh(m1):y2=yh(m1)
                 goto drawit
            case4:
                 x1=xh(m1):y1=yh(m1)
                 x2=(h(m3)*xh(m2)-h(m2)*xh(m3))/(h(m3)-h(m2))
                 y2=(h(m3)*yh(m2)-h(m2)*yh(m3))/(h(m3)-h(m2))
                 savx = x2 : savy = y2
                 goto drawit
            case5:
                 x1=xh(m2):y1=yh(m2)
                 x2=(h(m1)*xh(m3)-h(m3)*xh(m1))/(h(m1)-h(m3))
                 y2=(h(m1)*yh(m3)-h(m3)*yh(m1))/(h(m1)-h(m3))
                 goto drawit
            case6:
                 x1=xh(m3):y1=yh(m3)
                 if m > 1 then
                    x2 = savx : y2 = savy
                   else
                    x2=(h(m2)*xh(m1)-h(m1)*xh(m2))/(h(m2)-h(m1))
                    y2=(h(m2)*yh(m1)-h(m1)*yh(m2))/(h(m2)-h(m1))
                    end if
                 goto drawit
            case7:
                 if m > 1 then
                    x1 = savx : y1 = savy
```

```
                else
                 x1=(h(m2)*xh(m1)-h(m1)*xh(m2))/(h(m2)-h(m1))
                 y1=(h(m2)*yh(m1)-h(m1)*yh(m2))/(h(m2)-h(m1))
                 end if
              x2=(h(m3)*xh(m2)-h(m2)*xh(m3))/(h(m3)-h(m2))
              y2=(h(m3)*yh(m2)-h(m2)*yh(m3))/(h(m3)-h(m2))
              savx = x2 : savy = y2
              goto drawit
          case8:
              x1=(h(m3)*xh(m2)-h(m2)*xh(m3))/(h(m3)-h(m2))
              y1=(h(m3)*yh(m2)-h(m2)*yh(m3))/(h(m3)-h(m2))
              x2=(h(m1)*xh(m3)-h(m3)*xh(m1))/(h(m1)-h(m3))
              y2=(h(m1)*yh(m3)-h(m3)*yh(m1))/(h(m1)-h(m3))
              savx = x1 : savy = y1
              goto drawit
          case9:
              x1=(h(m1)*xh(m3)-h(m3)*xh(m1))/(h(m1)-h(m3))
              y1=(h(m1)*yh(m3)-h(m3)*yh(m1))/(h(m1)-h(m3))
              if m > 1 then
                 x2 = savx : y2 = savy
                else
                 x2=(h(m2)*xh(m1)-h(m1)*xh(m2))/(h(m2)-h(m1))
                 y2=(h(m2)*yh(m1)-h(m1)*yh(m2))/(h(m2)-h(m1))
                 end if
           drawit:
             x1 = int(x1)
             x2 = int(x2)
             y1 = int(y1)
             y2 = int(y2)
               line (x1,y1)-(x2,y2),colors(k)
          case0: next m

   noneintri: next k
   noneinbox: next i : next j
   circle (X(XC),Y(YC)),abs(X(XC)-X(xc-radius-1)),7
10202    RETURN
```

Conclusion

We have demonstrated that the FSIS instrument has the capability to accurately and rapidly analyze the full figure and surface roughness characteristics of grazing incidence surfaces for X-ray and hard UV imaging as well as for other cylindrical type aspheric surfaces over a broad range of wavelengths. This is possible in an affordable, reliable, and rugged instrument.We are currently in the process of obtaining grazing incidence optics from some national laboratories engaged in X-ray and UV imaging. Currently, there is no other optical instrument that we are aware of which can accurately measure both the full surface figure as well as the surface macro-roughness. The need for the immediate application of this optical surface measuring technology to chemical lasers, excimer lasers, laboratory X-ray lasers, gamma ray lasers, and free electron lasers is well documented. Other applications include general scanning of surfaces for quality control, materials defects analysis, and as a general instrument for aspheric optical quality control.

This research project demonstrated that the FSIS can work reliably in many types of environments and can be produced for under $65,000. Commercial production with user support and additional technical refinements can be marketed for less than $100,000. This is a small investment for such a versatile quality control instrument that can quantitatively determine whether an optical component that will be used in X-ray and UV imaging has been made to specification.